A water quality study of Barkers Creek, South Canterbury

A thesis submitted in partial fulfilment of the

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by H. J. Graham

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Photo: Looking southeast across the Barkers Creek catchment towards Geraldine

"When the well is dry, we know the worth of water"

- Benjamin Franklin

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Abstract

Diffuse nitrogen and phosphorus pollution from farming practices is a water resource management issue throughout New Zealand. Efficient management of diffuse pollutants requires a conceptual understanding of the relationship between groundwater and surface water in the catchment being investigated. With this knowledge, transfer pathways and "hot-spots" can be identified. Barkers Creek is a small sub-catchment of the Waihi River, in South Canterbury. Diffuse pollution is causing water quality issues within the Barkers Creek catchment that propagate to Waihi River.

There were three key components to this study. First, to characterise the hydrology, hydrogeology and hydrochemistry of Barkers Creek catchment. Then, to determine the main transfer pathways that nitrogen, phosphorus and sediment are entering Barkers Creek. Lastly, to understand temporal dynamics of nitrogen, phosphorus and sediment, and in particular the role storm flows have on these dynamics.

A field campaign was conducted to intensively monitor the surface water and groundwater regime in Barkers Creek over the year 2016-2017. Data collection occurred at different temporal resolutions, with parameters measured at all sites bimonthly intervals and a subset of sites measured at fortnightly and 5-minute intervals.

About of 44% of the flow in Barkers Creek is attributed to groundwater seepage occurring from the lower catchment, between McKeown Road (5.2 km upstream of the confluence) and the confluence with the Waihi River. Flow paths and residence times

between the recharge and discharge zones for groundwater appear to be short. There is evidence of anthropogenic influence, particularly on shallow groundwater, with elevated nitrate-nitrogen concentrations observed throughout much of the lower catchment. Nitrate-nitrogen and dissolved reactive phosphorus concentrations are typically higher in groundwater and some of the spring-fed drains than what is observed in Barkers Creek. There is also evidence of a natural phosphorus source in the catchment.

Of the nitrate-nitrogen load exported from the Barkers Creek catchment to the Waihi River, 20% is from diffuse groundwater seepage into the creek, 11% is from the Barkers Creek catchment upstream of McKeown Road and the remainder is from drain systems in the lower catchment, most of which are spring-fed. 56% of the total nitrate-nitrogen load is from the 3 (of 10) spring-fed drains in the lower catchment and can be considered the “hot-spots”. Nitrate-nitrogen loads during storm events do not differ significantly from loads during baseflow conditions and the spring-fed drains are a significant transfer pathway under all flow regimes.

Minimal DRP load in Barkers Creek comes from diffuse groundwater seepage. Barkers Creek upstream of McKeown Road contributed 13% of the total load export with the remainder attributable to export via spring-fed drains. The hotspots for DRP are 4 (of 10) spring-fed drains in the lower catchment. Export of phosphorus and sediment is sensitive to flow regime, with storm events being the major time of transport from Barkers Creek to the Waihi River.

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1 Introduction

1.1 Statement of problem

High nitrogen and phosphorus levels in freshwaters pose an adverse risk to ecological health, with extreme concentrations (nitrogen only) potentially having adverse effects on human health. In New Zealand, diffuse pollution arising from intensified farming has become a water resource management issue of national significance (Howard-Williams et al., 2010; Land and Water Forum, 2010).

The National Policy Statement for Freshwater Management (NPSFWM) contains “bottom lines” for nitrate-nitrogen concentrations to reflect this issue (Ministry for the Environment, 2017). In Canterbury, Environment Canterbury (the regional council) is working towards its obligations under the NPSFM and Canterbury Water Management Strategy (CWMS) through setting both quality and quantity limits under the ongoing sub-regional planning process for the Canterbury Land and Water Regional Plan (LWRP). The CWMS is a strategy developed by the Environment Canterbury to provide a framework to manage the water resource in the Canterbury region. Unlike the CWMS, the LWRP sets rules and policies providing direction for how water (and land) are managed throughout the Canterbury Region.

In Canterbury, increasing trends in nitrate-nitrogen concentration have been identified in groundwater (Alkhaier & Scott, 2013; Ford & Taylor, 2006; Hanson, 2002). The efficient management of nitrogen and phosphorus pollution in any catchment requires an understanding of where highly polluting activities are located; identification of environmental receptors; characterisation of the pathways via which pollutants are transported within the catchment and, ideally, knowledge of temporal dynamics of the system. If pollutant “hot-spots” can be mapped, then these can be targeted for strategic mitigation action.

In 2013, the results from a routine state of the environment monitoring exercise revealed a decline in water quality in the Waihi River (Kelly, 2015), notably in terms of nitrate, phosphorus and sediment. To investigate the potential source of the pollution, Environment Canterbury carried out a small targeted survey as an initial scoping attempt to identify the potential sources. This was undertaken between June 2013 and January 2014. The survey paid attention to surface water quality in Barkers Creek, which is a main tributary of the Waihi River.

Findings from that investigation suggested Barkers Creek to be a primary source of contaminant loads entering the Waihi River (Kelly, 2015). Nitrogen, phosphorus and sediment (measured as total suspended solids) were all identified as pollution issues impacting Barkers Creek. A limitation of that study was that it concentrated on surface water and did not examine the hydrogeological setting and the relationship between surface water and groundwater of the Barkers Creek catchment.

This study aims to build on the work undertaken by Kelly (2015) and understand/identify routes via which nitrogen and phosphorus are entering Barkers Creek. The work will constitute the first integrated study of surface water and groundwater in the Barkers Creek catchment, and the results will assist with developing a water quality management plan for the catchment.

1.2 Research aims and objectives

The primary aim of this research is to conceptually understand the combined hydrological and hydrogeological system of the Barkers Creek catchment and determine where the hotspots for nitrogen and phosphorus water pollutants are. This will allow characterisation of the pathways by which nitrogen and phosphorus pollution is entering the Barkers Creek. Building on the earlier findings of Kelly (2015) who noted nitrogen and phosphorus impacts seem to be concentrated in the lower reaches of Barkers Creek. I intend to identify the pathways by which these contaminants of concern are entering Barkers Creek and also to examine the spatio-temporal dynamics of the pollution.

The objectives of this research are to:

1. Undertake a field campaign to intensively monitor the surface water and groundwater regime in the Barkers Creek catchment;
2. Understand and characterise the hydrology/hydrogeology/hydrochemistry of the Barkers Creek catchment and examine how it controls surface water quality in Barkers Creek;
3. Determine the main transfer pathways via which nitrogen and phosphorus (contaminants of concern) is entering Barkers Creek in the lower reaches, and calculate those loads;
4. Understand the impact storm flows have on phosphorus and total suspended solids (TSS) loads in Barkers Creek.

1.3 Thesis structure

This thesis is structured as follows:

- Chapter 2: literature review of nutrients in water and their transfer pathways
- Chapter 3: detailed description of the study area – including climate, geology, soils, land use, hydrology and water use and development
- Chapter 4: descriptions of the field and analytical research methodology
- Chapter 5: presents results from data collected during this research
- Chapter 6: interpretation of the results, presenting a hydrodynamic understanding of the catchment and an understanding of transfer pathways
- Chapter 7: the main findings of this study.

2 Literature review

Diffuse transfer of nutrients (nitrogen and phosphorus) and sediment in agricultural catchments is controlled by the mobilisation of sources and their delivery to surface water. Excess nitrogen and phosphorus diffusion from agricultural catchments can pose a significant threat to ecological health in surface water. The understanding and control of nitrogen and phosphorus losses is key in managing diffuse pollution.

2.1 Nitrate as a contaminant of concern

2.1.1 The nitrogen cycle

Nitrogen (and phosphorus) is a limiting nutrient in aquatic environments and is essential for plant and animal nutrition. The movement and transformation of nitrogen through the biosphere can be described by the nitrogen cycle (see Figure 2-1). The atmosphere is comprised of approximately 78% nitrogen in the form of nitrogen gas (N_2). The nitrogen gas needs to be combined with hydrogen or oxygen before it can be taken up by higher plants, which are in turn consumed by animals (Canter, 1997; Rivett et al., 2008).

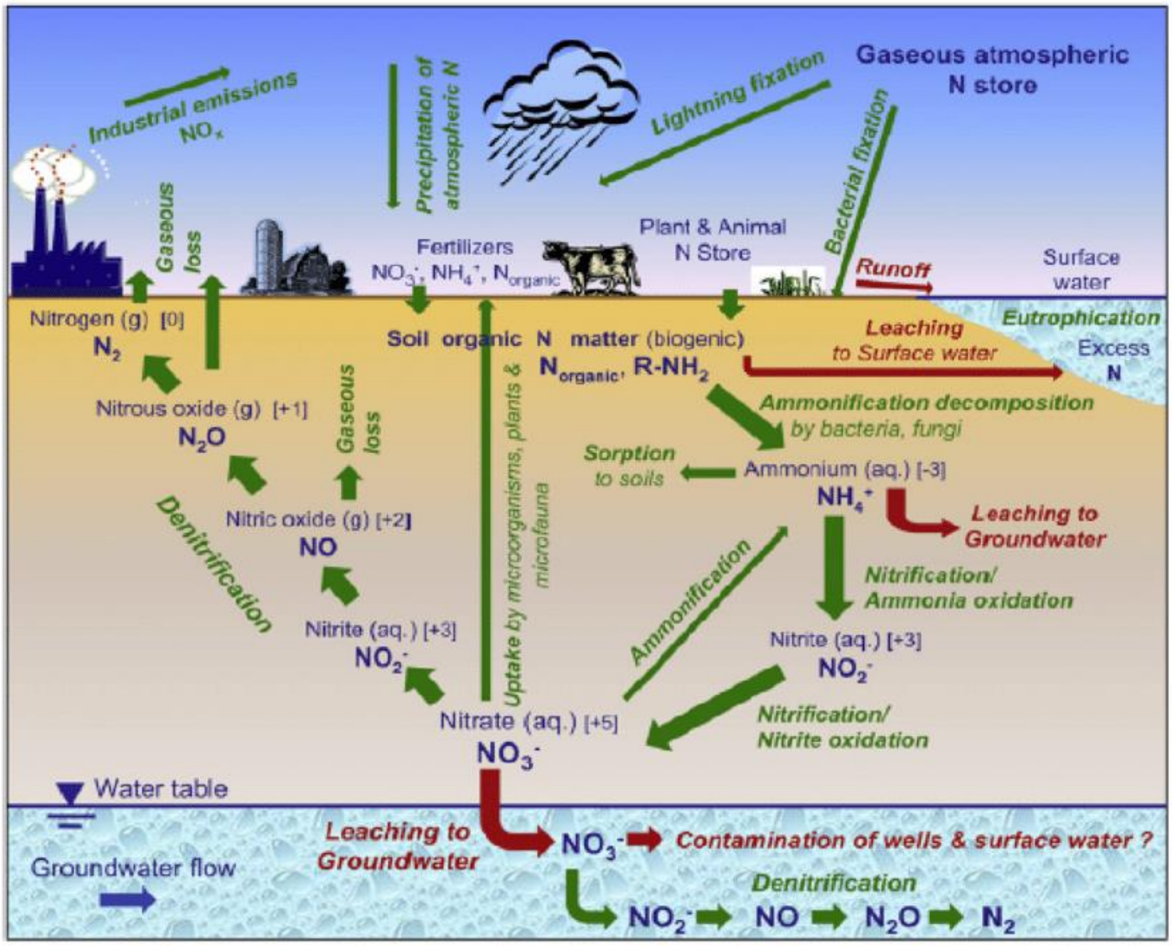

Figure 2-1: The nitrogen cycle (Rivett et al., 2008)

In addition to biomatter, oceans, surface water, groundwater, rock and soils also serve as nitrogen reservoirs. Chemical and biochemical processes act as a mechanism to transfer nitrogen between the various reservoirs. Human intervention have altered these processes, influencing the volume of nitrogen stored and transferred in the different reservoirs over time (Canter, 1997; Hatch et al., 2002; Vitousek et al., 1997). The Haber-Bosch process is a key intervention, and the production of nitrogen based fertiliser has significantly altered the nitrogen budget of the planet due to a large increase in reactive nitrogen (Erisman et al., 2008).

While nitrogen can exist in several forms, ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-) are the reactive forms of nitrogen which pose the greatest risk to water quality

(Hatch et al., 2002). Nitrate is the most oxidised from of nitrogen and is highly sensitive to oxidation-reduction (redox) reactions (Canter, 1997; Rivett et al., 2008). Nitrate is the most common source of nitrogen in groundwater and surface water because it is soluble and highly mobile (Canter, 1997). This mobility complicates the management of nitrate. Surface water and shallow groundwater are particularly susceptible to nitrogen contamination.

Nitrification

Nitrification is a two-stage microbial oxidation process where ammonium is converted to nitrite then nitrate (Equation 1). Aerobic conditions are required for nitrification to occur and is facilitated by autotrophic organisms (Canter, 1997). The first stage of the reaction in equation 1 is the rate determining stage. This is because nitrite is unstable and as such typically does not accumulate in the environment (Rivett et al., 2008).

$$\boldsymbol{NH_4^+ + 2O_2 \frac{Nitrosomonas}{bacteria} \rightarrow NO_2^- + 4H^+ + O_2 \frac{Nitrobacter}{bacteria} \rightarrow NO_3^+ + H_2O + 2H^+}$$

Equation 1

Denitrification

Denitrification is important to the nitrogen cycle and describes the biological reduction of nitrate and nitrite to nitrogen gas, a reverse of nitrification (Canter, 1997). Denitrification is considered to be the most significant nitrate removal process (Burgin & Hamilton, 2007; Rivett et al., 2008). Denitrification requires heterotrophic bacteria combined with organic compounds (e.g. dissolved organic carbon) which provide the bacteria with an energy and carbon source. It is also possible for denitrification to occur through autotrophic bacteria which obtain energy from oxidising inorganic species (Rivett et al., 2008). The occurrence of denitrification in general is aided by the absence of oxygen, presence of organic carbon and sulphur (e.g. sulphate) or iron (Canter, 1997; Rivett et al., 2008).

2.2 Phosphorus as a contaminant of concern

Phosphorus is a reactive chemical element that readily combines with oxygen to form compounds known as phosphates (which contain the phosphate ion, PO_4^{3-}). Phosphates are naturally found in both inorganic minerals (i.e. rocks) and in some organic matter (e.g. DNA, RNA, ATP, phospholipids). Phosphorus can also be found in various dissolved forms in water, including inorganic phosphate and soluble organic compounds containing phosphorus.

Phosphorus is sourced from both natural and man-made sources. Natural sources include rocks, soils, plant and animal matter. Man-made sources are the most common and include fertiliser use in agricultural areas and waste disposal. Phosphorus is cycled in the environment over relatively short timescales in soils, plants and animals and over much longer timescales in mineral deposits. Phosphorus is accumulating in soils because of both natural and human induced sources.

Although the phosphate ion is negatively charged (like the nitrate ion) it interacts differently with soil. Typically, phosphorus adsorbs onto the soil particles and becomes immobile (Domagalski & Johnson, 2011; Tesoriero et al., 2009). Phosphorus can have negative impacts on surface water ecosystems and cause increases in biomass of algae and phytoplankton, shifts in phytoplankton from non-toxic to toxic species (e.g. cyanobacteria), changes in macrophyte species composition and biomass, decreases in water transparency and oxygen depletion (Carpenter et al., 1998). Therefore, discharging of phosphorus-enriched groundwater to surface water can cause nuisance growth in waterways, even at low concentrations.

In both groundwater and surface water systems, phosphorus comes from many sources. Phosphorus can enter surface water due to it adsorbing to sediment which is predominantly exported to surface water during runoff events (Sharpley et al., 1994). Phosphorus concentrations in runoff are impacted by fertiliser application and other land management practices (e.g. stock access to waterways). Both dissolved and particulate phosphorus can exist in water systems (Wetzel, 2001). Orthophosphate; polyphosphates, organic colloids; and phosphate esters are all forms of dissolved phosphorus, while phosphorus present in organisms, and mineral phases of sediment are forms of particulate phosphorus. Of these forms orthophosphate (PO_4^{3-}) is the most common form of phosphorus found in surface water and groundwater.

2.3 Nutrient transfer pathways

The management of nitrogen, phosphorus and sediment requires a fundamental understanding as to how they are transferred to the receiving environment (i.e. surface water). This allows targeted management to be directed towards the pathways with the largest influences on the receiving environment. Catchment-specific factors (e.g. geomorphology and hydrology) impact the importance of groundwater and near surface nutrient transfer pathways.

Nutrient transfer can be largely categorised into four pathways: 1) overland flow, 2) interflow, 3) shallow groundwater and 4) deep groundwater (Archbold et al., 2010; Mellander et al., 2012). This four-category conceptual model is shown in Figure 2-2. In addition to these four pathways, artificial drainage (e.g. tile or mole drains) are an additional ‘bypass’ pathway. This pathway is important in a catchment with artificial drainage as it can expedite the transport of high nutrient bearing drainage water to surface water.

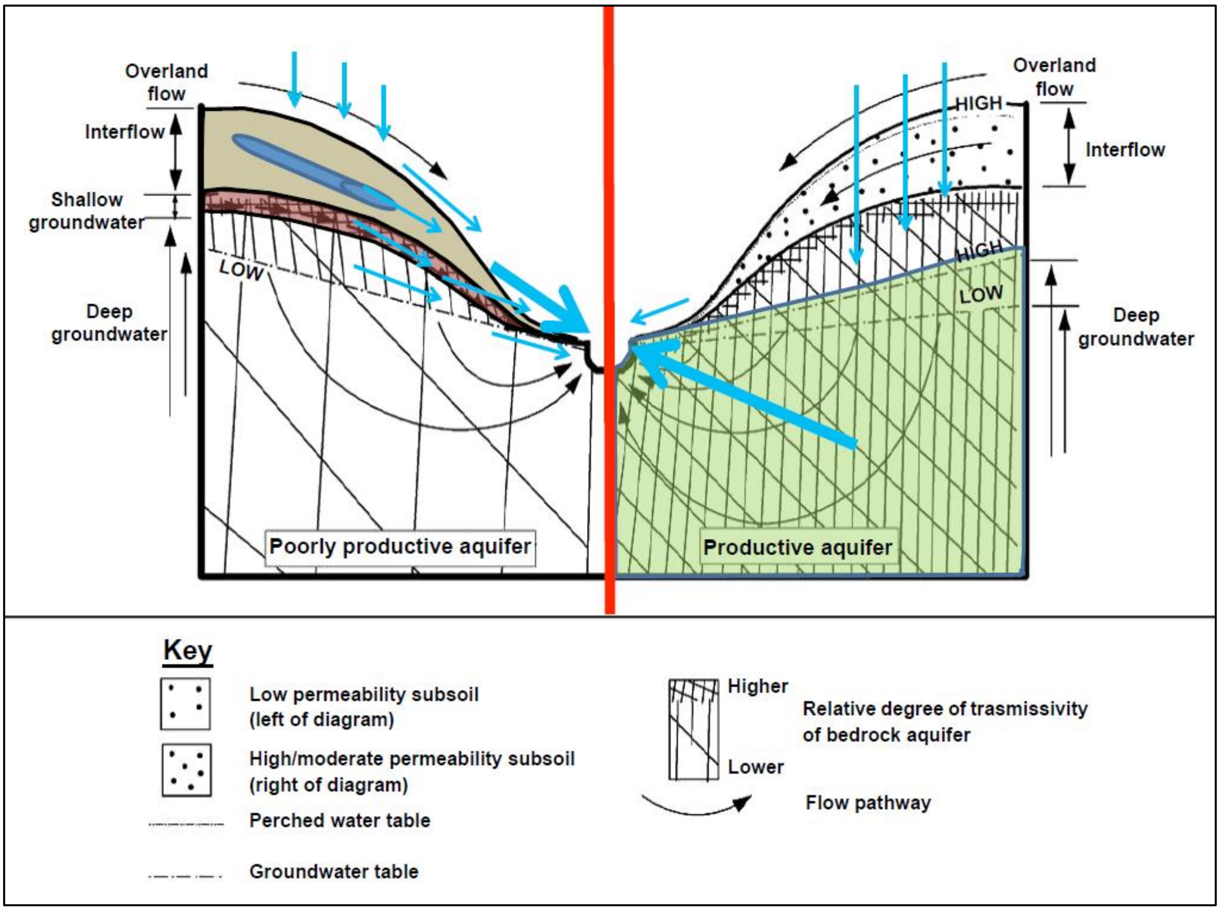

Figure 2-2: Conceptual model of nutrient transfer pathways in a poorly productive aquifer (left) and a productive aquifer (right) (Archbold et al., 2010)

The dominant transfer pathway for nitrogen (via agricultural practices) is via leaching into groundwater and subsequent transfer to surface water via sub-surface pathways (Mellander et al., 2012; Stenger et al., 2018). Jiao et al. (2012) showed that nitrogen loss may also occur via surface runoff. While surface runoff is a less dominant transfer pathway, it is important when trying to understand how nutrients are transferred within a catchment (Jiao et al., 2012). Nitrogen attenuation along the transfer pathways can impact the nutrient concentrations that reach the receiving environments.

Due to the adsorbing nature of phosphorus, phosphorus loss to surface water has therefore previously been associated primarily with surface runoff. In certain conditions however, phosphorus can dissolve and leach down through the soil to the groundwater. Recent research (Dodd & McDowell, 2014; Domagalski & Johnson, 2011; McDowell et al., 2015) suggests that there could be more phosphorus leaching to New Zealand groundwater from agricultural practices than previously thought.

Under baseflow conditions, dissolved phosphorus in surface water is exchanged with stream bed sediments (Palmer-Felgate et al., 2009). Additional inputs can come from groundwater and animal faeces (McDowell et al., 2009). Gaining surface water reaches are fed by groundwater. Stream bed sediments, under oxic conditions, will attenuate phosphorus input from groundwater unless the rate of groundwater upwelling exceeds the kinetic affinity of sediment, or if the sediment is saturated in phosphorus (McDowell et al., 2018). Rainfall events are a key pathway via which sediment-bound phosphorus (and sediment itself) is lost from land to surface water (Palmer-Felgate et al., 2009).

2.4 Nutrients in Canterbury

Nitrogen occurs naturally in groundwater and Morgenstern and Daughney (2012) suggest that natural background levels in oxic groundwater are below 0.25 mg/L in New Zealand groundwater. Morgenstern and Daughney (2012) went on to identify that nitrogen concentrations less than 2.5 mg/L can be considered low and reflective of low intensity land-use water. Higher concentrations can be caused by leaching from agricultural land practices, which proceeded after the 1950’s (post-war). For assessing the magnitude of impact nitrogen and phosphorus are having on water quality, the following guidelines and limits are a useful tool.

As much as 47% of New Zealand drinking water is sourced from groundwater (Ministry for the Environment & Stats NZ, 2017). It is therefore important that groundwater in New Zealand is of high quality. The New Zealand Ministry of Health has set a maximum acceptable value of 11.3 mg/L of nitrate-nitrogen in drinking water (Ministry of Health, 2018). While the Ministry of Health have set a maximum acceptable value based on human health factors, Environment Canterbury intend to set maximum and average acceptable concentrations based on both health and environment (toxicity) factors.

At present, Environment Canterbury has not set any water quality limits in the Orari-Temuka-Opihi-Pareora water zone for surface water through regional plans specific to the area covered by this study. The existing Opihi River Regional Plan (2001), which covers the Barkers Creek catchment, did not prescribe any water quality limits. There is a sub-regional planning process currently being undertaken by Environment Canterbury which includes the Opihi catchment and intends to prescribe water quality limits. The intention is to adopt the existing regional limits as set out in the current Land and Water Regional Plan (Gray, 2017). As such, the discussion in the next paragraph refers to the limits prescribed in Schedule 5 and 8 of the Land and Water Regional Plan.

In surface water, Schedule 5 prescribes the receiving water standards for surface water (Environment Canterbury, 2018). Schedule 5 water quality relevant to this study are shown in Table 2-1. Hill-fed lower limits are relevant to Barkers Creek, and the spring-fed plains limits are relevant to the spring-fed drains the feed Barkers Creek in the lower catchment.

Table 2-1: Land and Water Regional Plan Schedule 5 receiving water standards (Environment Canterbury, 2018)

Water quality class	pH	Dissolved inorganic nitrogen (mg/L)	Dissolved reactive phosphorus (mg/L)
	Shall be between	Shall be less than	Shall be less than
Hill-fed lower	6.5-8.5	0.47	0.006
Spring-fed plains	6.5-8.5	1.5	0.016

In groundwater, Schedule 8 of the Land and Water Regional Plan prescribes the maximum nitrate-nitrogen to be less than 11.3 mg/L and the annual average nitrate-nitrogen concentration to be less than 5.65 mg/L (Environment Canterbury, 2018).

There are no health based guidelines for phosphorus in freshwater. The New Zealand Periphyton Guideline (2000) provides dissolved phosphorus concentrations related periphyton biomass and percent cover thresholds:

- Unenriched – <0.003 mg/L
- Enriched – <0.003 – 0.009 mg/L
- Excessive – >0.03 mg/L

3 The study area

3.1 Overview

The Barkers Creek catchment is located approximately 3 km north of Geraldine (Figure 3-1). Barkers Creek is a small sub-catchment of the Waihi River catchment. The surface water catchment for Barkers Creek covers an area of approximately 34 km^2 (3,400 ha). This is a small component of the total Waihi River catchment which covers an area of 166 km^2.

The surface water catchment is constrained by the Waihi River to the north, and the Hae Hae te Moana River catchment to the south. Barkers Creek itself flows from the foothills to the west and terminates at its confluence with the Waihi River to the east. Surface water and groundwater are both important resources and used for irrigation, domestic and stockwater supply with sheep and beef being the dominant land use.

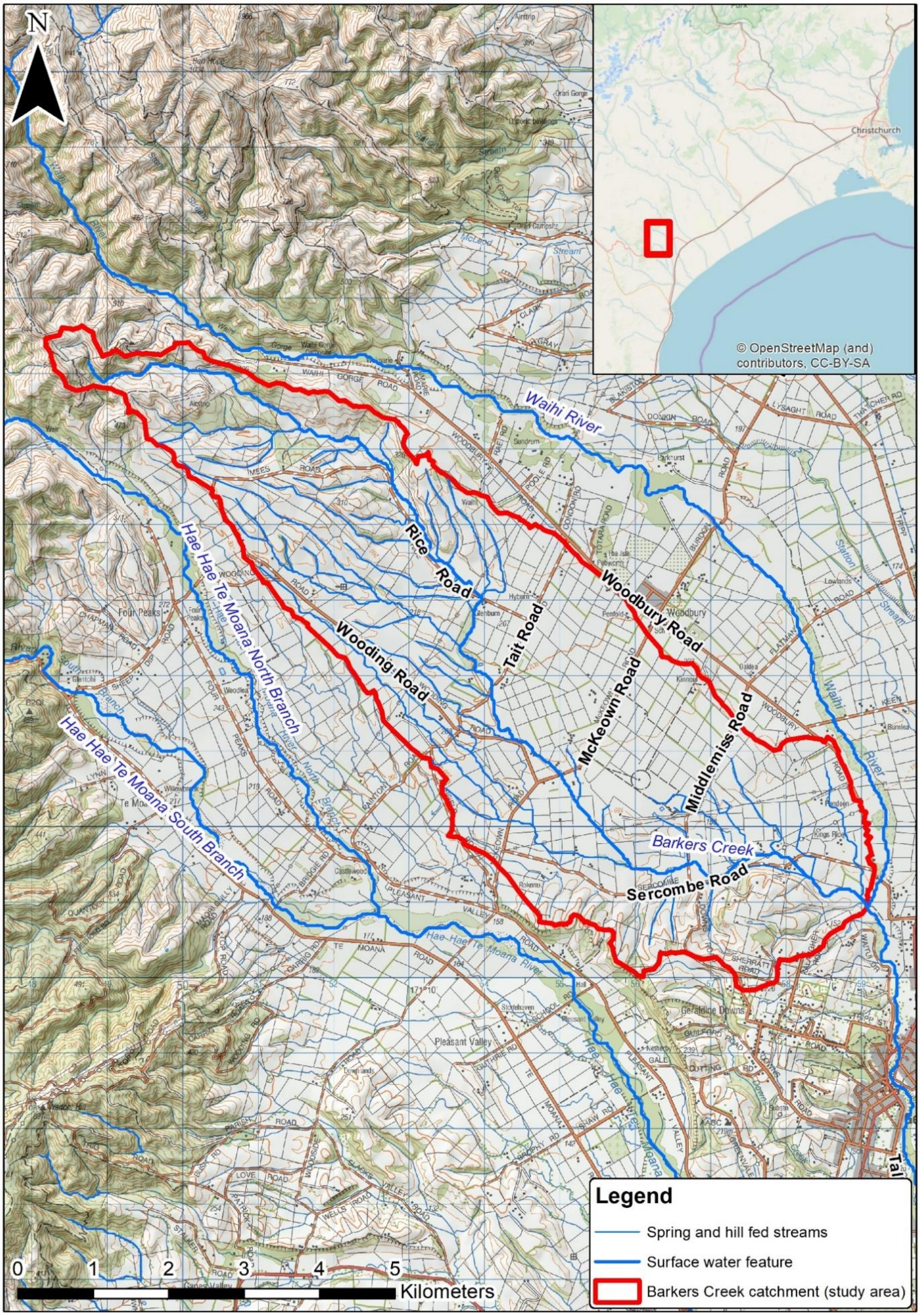

Figure 3-1: Location map of study area, Barkers Creek catchment

3.2 Topography

The topography of the Barkers Creek catchment is variable (Figure 3-2). To the west of Tait Road, the catchment landscape begins to modify into steepening foothills, rising to a maximum elevation of 625 m. East of Tait Road the catchment flattens out considerably into a plain setting with an elevation change of 70 m[1] between Tait Road and Barkers Creeks confluence with the Waihi River (5.5 km lateral distance). On these plains, there are two small mounds (both with a maximum elevation of approximately 190 m) which rise 30 m above the flat plains. To the south of Sercombe Road is a large basalt hill (known locally as the Geraldine Downs; 215 m elevation) that constrains the southern margin of the lower Barkers Creek catchment (discussed in more detail in Section 3.4).

[1] 210 m at Tait Road and 140 m at Barkers Creeks confluence with the Waihi River.

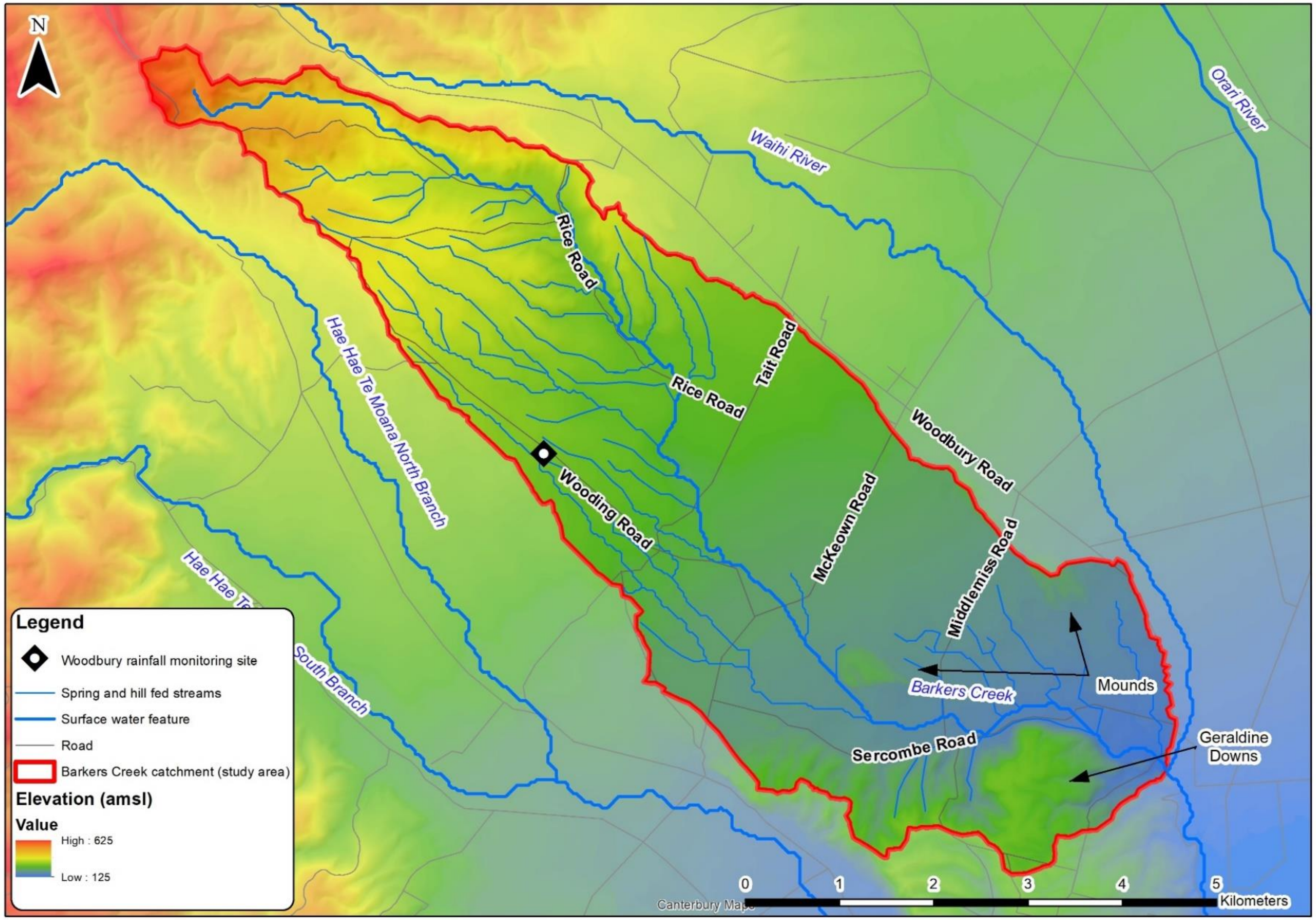

Figure 3-2: Map showing the topography of the Barkers Creek catchment

3.3 Rainfall

Rainfall is an important recharge source to both surface water and groundwater. Environment Canterbury operates a rainfall station within the Barkers Creek catchment. Records for this site start in 2008 (Environment Canterbury site number 410111 – Woodbury; location shown on Figure 3-2), with 11 years of data available to this study. To gain insight into how reflective this short record was of long-term rainfall, the site needed to be compared to another rainfall monitoring site with a longer record (ideally at least 30 years). The rainfall monitoring site at the Orari Gorge climate station (located approximately 7.5 km to the north) operated by the National Institute of Water and Atmospheric Research (NIWA) is a suitable site for comparison and has been in operation since 1899. While the Orari Gorge station has a higher average annual rainfall (around 270 mm more annually) a similar monthly rainfall pattern can be observed between the two sites. Given these similarities in the records, the 11-year record at the Environment Canterbury is considered to be reflective of conditions in the Barkers Creek catchment.

Average annual rainfall in the Barkers Creek catchment is 870 mm/year and across the 11 year data record ranges from 600 mm/year to 1280 mm year (Figure 3-3). Average monthly rainfall data for the Barkers Creek catchment is greatest through the months October to April and lowest through the months May to September (Figure 3-4). On average, April is typically the wettest month and September the driest. However, the maximum and minimum values on Figure 3-4 show that there can be significant variability around the average. Given the location of this rainfall station is in the upper extents of the Barkers Creek catchment (elevation of 235 m) there is potential for rain shadow to be occurring. That is, higher rainfall in the foothills (upper catchment) and lower rainfall in the lower catchment. Whilst there are no other rainfall monitoring sites nearby, given the size of the Barkers Creek catchment rain shadow is assumed to not be significant in the catchment and rainfall is expected to be similar in both the upper and lower catchments

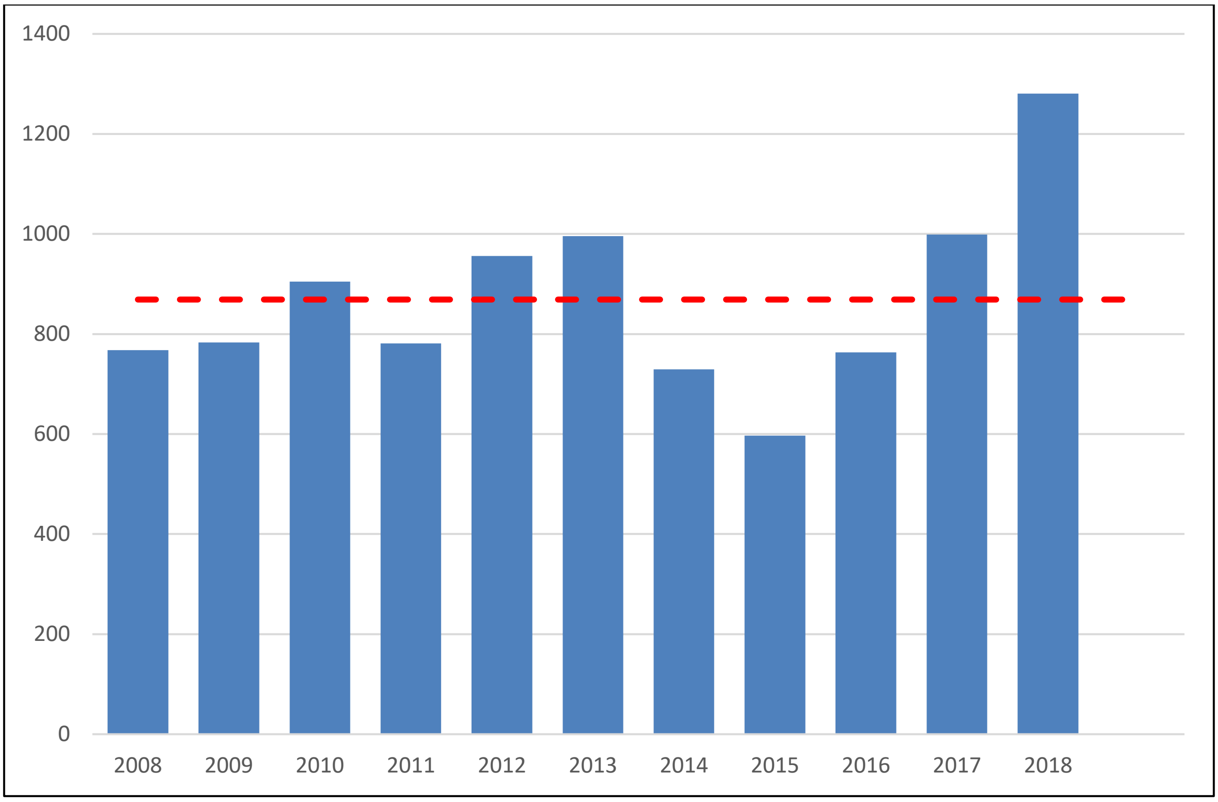

Figure 3-3: Annual rainfall totals from rainfall monitoring site 410111 - Woodbury. Red dashed line represents the average annual rainfall.

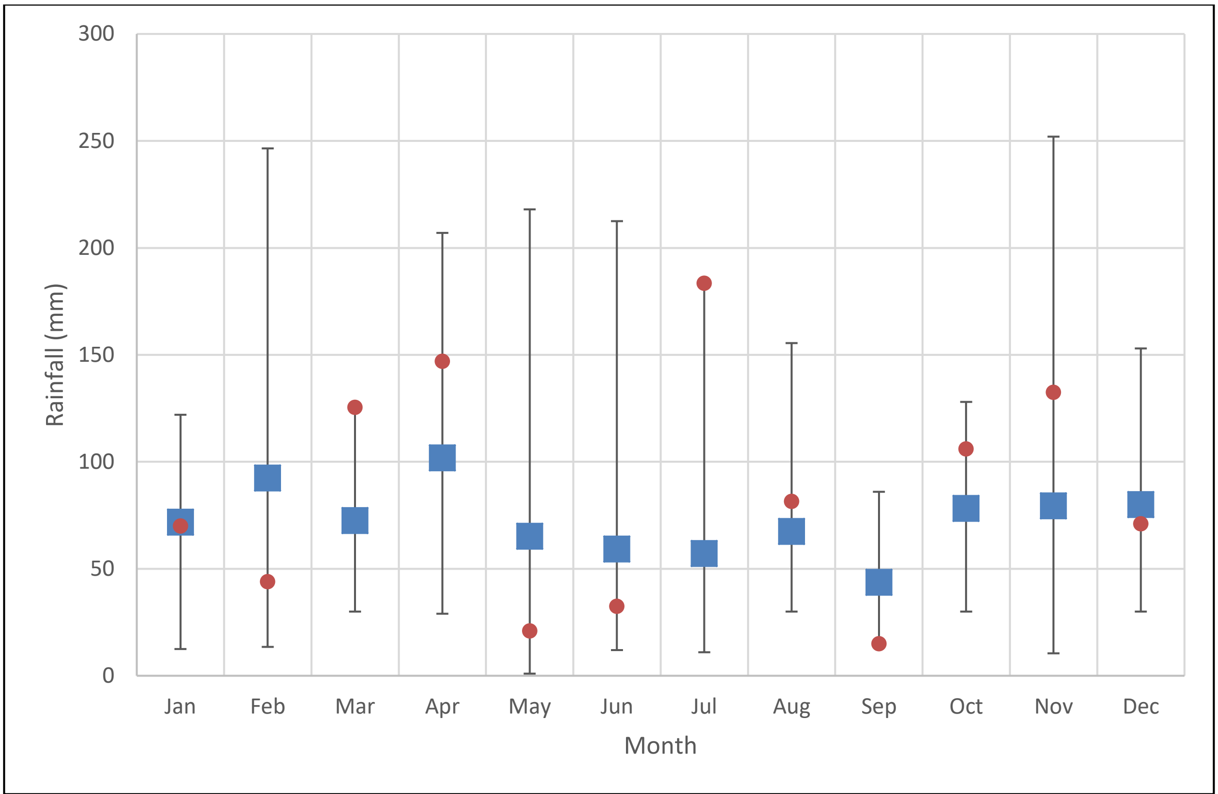

Figure 3-4: Monthly average rainfall (blue squares) from rainfall monitoring site 410111 – Woodbury (period 2008-2018). Black bars indicate maximum and minimum monthly values. Red dots represent monthly rainfall observed during thesis fieldwork

3.4 Geology and structure

3.4.1 Geologic structure

There are a number of active and inactive faults across the Barkers Creek catchment (Figure 3-5). Beyond these faults, the only other geologic structure of note is an anticline mapped by Cox and Barrell (2008) which runs on a southwest to northeast trajectory across the bottom of the catchment.

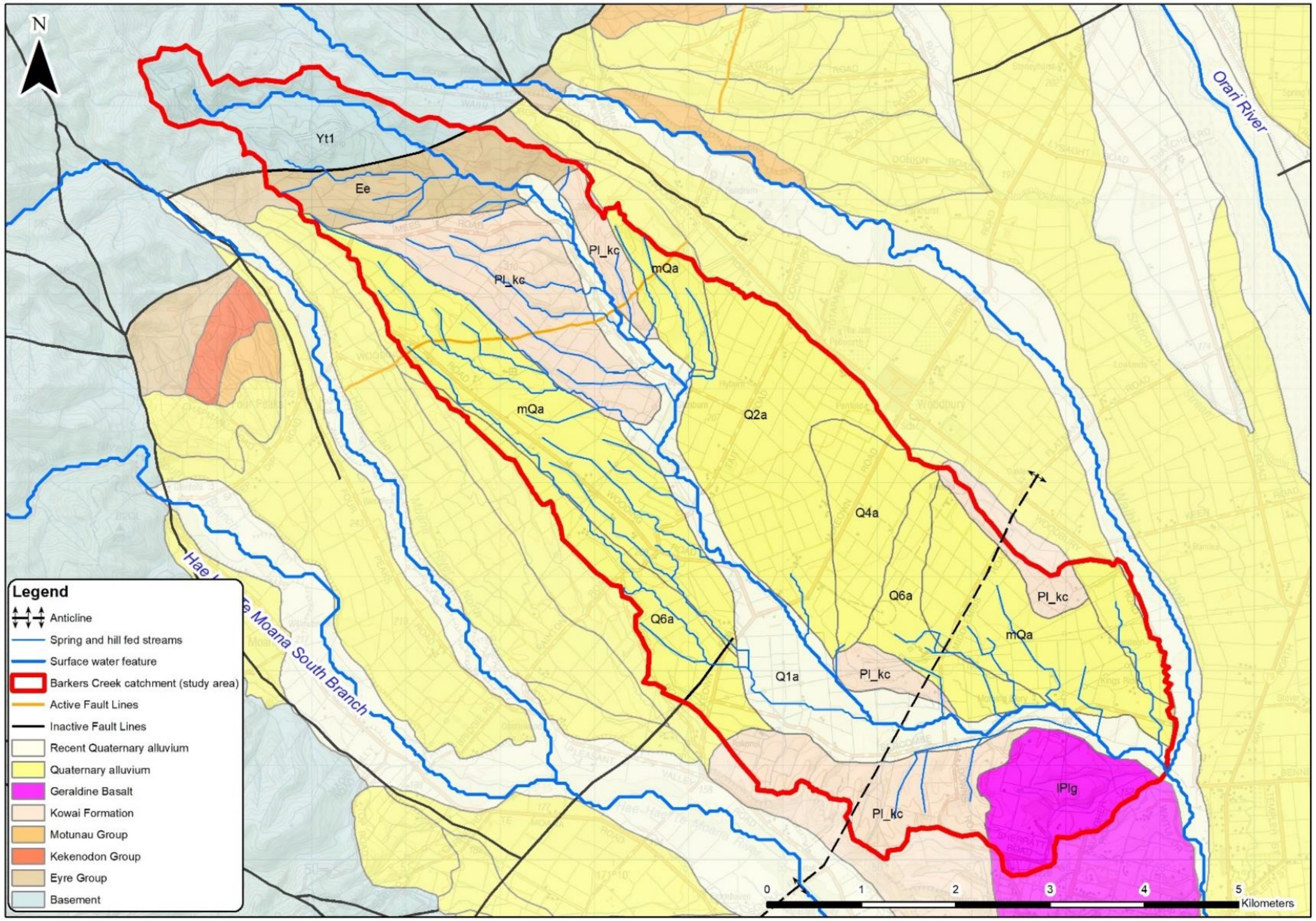

Figure 3-5: Geological map of the Barkers Creek catchment based on geological QMAP sheets by Cox and Barrell (2008). Formations have been ordered from youngest to oldest

There is little obvious surface expression of this anticline remaining today, likely eroded and/or covered by Quaternary alluvium. There are two outcrops of Kowai Formation forming small mounds that may be the remaining surface expression of the anticline. This anticline likely means that cover formation units are closer to the ground surface than normal, potentially impacting groundwater flow paths at the bottom of the catchment. The proximity of cover formations to the ground surface is potentially evident in the borelogs for J37/0137 and BY19/0035 (see Appendix A for borelogs), which are both located approximately 700 m to the west of the mapped expression of the anticline. The borelog (logged by the driller) for J37/0137 has gravels to 20 m at which point the log has clay until the log terminates at 54 m. This clay could be reflecting a cover formation unit.

3.4.2 Geology

Understanding geology is an important component in understanding surface water and groundwater, whether it be quantity or quality aspects. The geology of the Barkers Creek catchment is described and mapped in the Cox and Barrell (2008) QMAP sheet and report by GNS Science. Figure 3-5 shows the surface geology and Table 3-1 outlines the geological units present in the catchment. The stratigraphic sequence can be subdivided into three groups from youngest to oldest:

1. Quaternary (mid-Pleistocene and Holocene) age alluvial deposits,
2. Cretaceous to Pliocene age sediments (referred to in this study as *cover formations*), and
3. Late Jurassic basement rock.

These formations are described below in order of geological age (youngest to oldest).

Table 3-1: Geological units within the Barkers Creek catchment

Geological era	Geological period	Geological epoch	Group/formation name	Lithological description
Cenozoic	Quaternary (2.6 Ma – present)	Holocene (11.7 Ka – present)	Quaternary alluvium - river gravels, loess, swamp and beach/estuary deposits	
		Pleistocene (2.6 Ma – 11.7 Ka)		
	Neogene (23 – 2.6 Ma)	Pliocene (5.3 – 2.6 Ma)	Geraldine Basalt	Olivine and hypersthene basalt
			Kowai Formation	Interbedded conglomerate and sandstone
		Miocene (23 – 5.3 Ma)	Motunau Group	Claystone, siltstone and sandstone, with minor conglomerate and lignite seams
				Sandy siltstone and fine sandstone
			Kekenodon Group	Sandy limestone and glauconitic sandstone
	Paleogene (66 – 23 Ma)	Oligocene (34 – 23 Ma)	**Marshall paraconformity**	
		Eocene (56 – 34 Ma)	Eyre Group	Quartzose sandstone, muddy limestone and calcareous mudstone
			Widespread unconformity/disconformity	
		Paleocene (66 – 56 Ma)	Eyre Group	Quartzose sandstone, muddy limestone and calcareous mudstone
				Quartzose sandstone and mudstone
Mesozoic	Cretaceous (145 – 66 Ma)	Late (101 – 66 Ma)	**Regional unconformity**	
			Undifferentiated sedimentary rocks	
		Early (145 – 101 Ma)	**Regional unconformity**	
	Permian (299 – 250 Ma)		Basement rock - greywacke (sandstone) and argillite (mudstone)	

Quaternary alluvium

Quaternary alluvial deposits (alluvium) consist mainly of sandy and silty gravel and are found throughout the Barkers Creek catchment (Figure 3-5). More recent alluvium of Holocene age occurs along the modern day surface water channels and flood plains.

Quaternary alluvium is an important hydrogeological unit throughout New Zealand and Canterbury in particular. The Quaternary alluvium in the Barkers Creek catchment are generally older (Q2, Q4 and Q6) compared to the Quaternary alluvium in the Waihi River catchment, and much of the Canterbury Plains.

Loess

Loess is a fine-grained windblown silt deposit (Cox & Barrell, 2008). While loess has not been mapped in the Barkers Creek catchement by Cox and Barrell (2008), loess deposits are known to occur within Quaternary alluvium in the Barkers Creek catchment. Geological unit Q6a has been described as having some loess cover while unit mQa has been described as having up to three loess layers (Forsyth, 2001). Loess typically has a low permeability (Raeside, 1964) and therefore can limit land surface recharge (LSR) to groundwater and promote runoff to surface water. Fragipan (discussed in Section 3.5) is common in loess deposits and can further impact recharge to the groundwater system (Forsyth, 2001).

Cover formations

Cover formations in the Barkers Creek catchment are found to outcrop throughout the catchment. However, cover formations older than the Kowai Formation only outcrop in the foothills where they have been thrust to the surface by faults. Cover formations are also expected to underlie the Quaternary alluvium and loess deposits, although due to the limited exploration of groundwater at depth this can only be inferred. The cover formations are spread across six geological groups/formations, which range in age from Cretaceous to Neogene (Table 3-1).

The Geraldine Basalt is the youngest of the cover formations. This formation is late Pliocene in age and overlies the Kowai Formation (Cox & Barrell, 2008). This basalt extrusion is likely related to Mt Horrible and the Timaru Basalt sequence (Barrell & Strong, 2012). The basalt will be acting as a barrier to both surface water and groundwater flow due to its impermeable nature.

The Kowai Formation is typically described as a conglomerate of well-rounded gravel in a fine to course angular sandy matrix. Cox and Barrell (2008) describes the Kowai Formation as composed of Torlesse-derived fluvial and shallow marine conglomerate inter-bedded with sandstone and mudstone. This formation is found extensively throughout the Barkers Creek catchment (Figure 3-5) and underlies the Quaternary alluvium in places where the Geraldine Basalt is not present. The Kowai Formation is an important hydrogeological unit, as is also the case in other parts of Canterbury, i.e. South Canterbury: (Forsyth, 2004); Culverden Basin: (Poulsen, 2012) and Waipara: (Lloyd, 2002).

The Motunau Group contains sedimentary deposits (siltstone, sandstone and claystone) which sit atop the Kekenodon Group which is comprised of sandstone and limestone. A regionally extensive surface or erosion of non-deposition exists at the base of the Kekenodon Group, and marks the Marshall Paraconformity (Cox & Barrell, 2008). Underlying the Kekenodon Group is the Eyre Group. The Eyre Group is comprised of marine sandstone, limestone and mudstone. These geological units outcrop in the headwaters of Barkers Creek

Basement rock

Basement rock (greywacke) outcrops at the most inland point of the Barkers Creek catchment (Figure 3-5). This basement rock provides the underlying structure for the cover formations and Quaternary alluvium. Basement rock is predominantly Permian in age and forms part of the Rakaia Terrane. The Rakaia Terrane is comprised of quartzofeldspathic sandstone and argillite (Cox & Barrell, 2008).

3.5 Soils

Soil type plays an important role in understanding how water is held, evaporates and/or moves through the soil profile into groundwater and surface water. With respect to nitrogen and phosphorus, soil drainage properties become key in understanding potential transfer pathways. Within the Barkers Creek catchment, poorly drained soil types are most common (Figure 3-6).

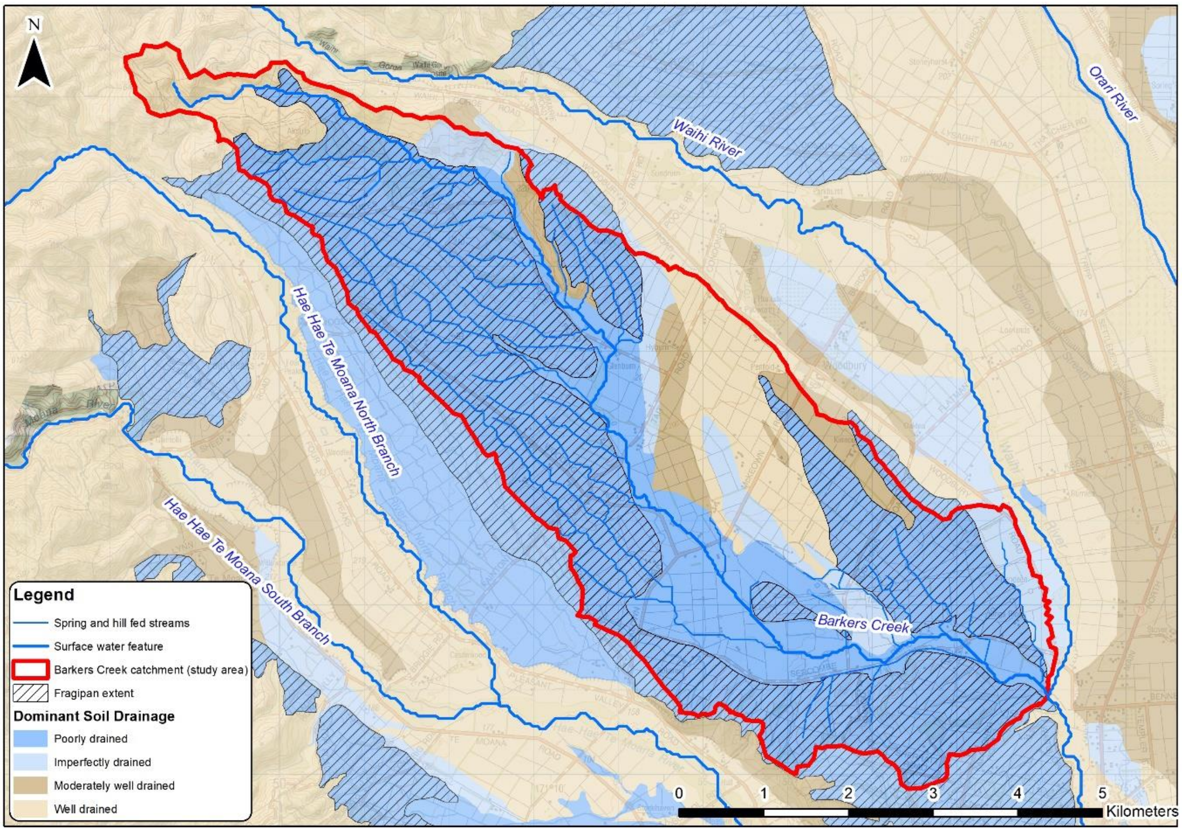

Figure 3-6: Map showing the soil groups of the Barkers Creek catchment (from S-map soil database from Landcare Research, accessed December 2018)

There is significant coverage of fragipan across the poorly drained soil types in the Barkers Creek catchment (Figure 3-6). Fragipan is an altered subsoil layer with high bulk density with high strength when dry. Fragipan restricts root penetration, land use and has the potential to severely limit LSR to the groundwater system (Poulsen, 2013). Fragipan are typically developed in loess deposits that occur in seasonally dry climate with an average annual rainfall less than 950 mm (Berger et al., 2002; Taylor & Pohlen, 1970). Fragipan promotes runoff to surface water. The soil groups not containing fragipan layers more readily transmit water and have a higher nutrient leaching potential to groundwater.

As Figure 3-6 shows, the Barkers Creek catchment reflects a soil (and geomorphological) anomaly in the Waihi catchment with increased coverage of fragipan deposits and poorly drained soils. This is probably because the catchment is outside the main area of influence of the Rangitata, Orari and Waihi river systems that formed the nearby Canterbury Plains.

3.6 Land use

Current land use in the Barkers Creek catchment is primarily agricultural (Table 3-2 and Figure 3-7). Animal grazing dominates land use within the catchment with sheep, beef and deer grazing comprising 80% of the land use. Dairy farming brings land use cover by livestock in the catchment to 93%. While there are several properties which carry dairy cattle, there is only one milking platform and one irrigated property in the catchment.

Table 3-2: Dominant land use within the Barkers Creek catchment (data source AgriBase™)

Land use	Area covered (ha)	Area covered (%)
Sheep and beef	2113	63%
Deer	312	9%
Dairy	280	8%
Grazing other peoples' stock	264	8%
Irrigated dairy	129	4%
Lifestyle block	86	3%
Arable	78	2%
Forestry	77	2%

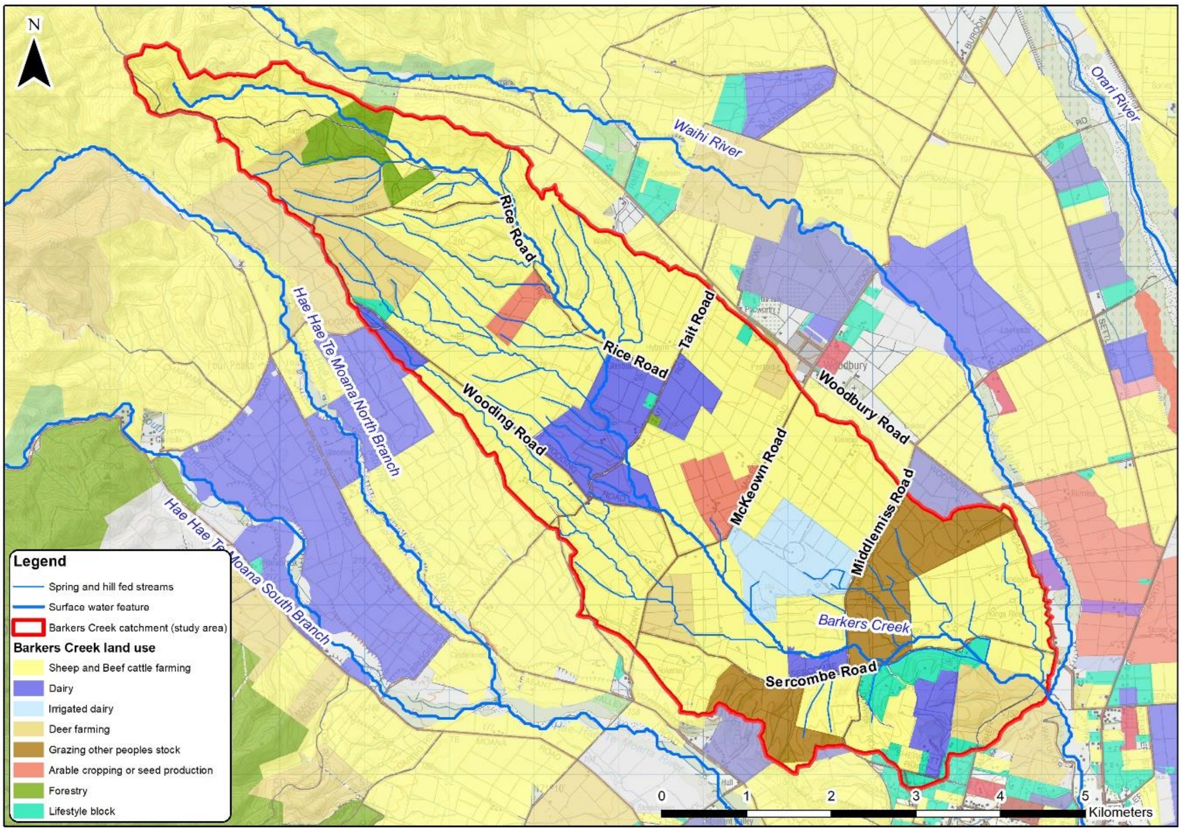

Figure 3-7: Dominant land use in the Barkers Creek catchment (simplified from AgriBase™, accessed December 2018 and aerial photographs where there were data gaps)

3.7 Surface water

Barkers Creek is the major surface water feature in the catchment. It is fed by several spring-fed and hill-fed tributaries (Figure 3-8), some which are perennial and others are ephemeral. Unlike the Waihi River to the north and Hae Hae Te Moana River to the south, Barkers Creek has a relatively small catchment area originating low in the western foothills. Barkers Creek emerges from the foothills and flows eastward across the plains and into the Waihi River. While the majority of Barkers Creek itself has been fenced to prevent stock access, many of the spring-fed and hill-fed drains remain unfenced. Little flow data existed for the Barkers Creek catchment prior to this study.

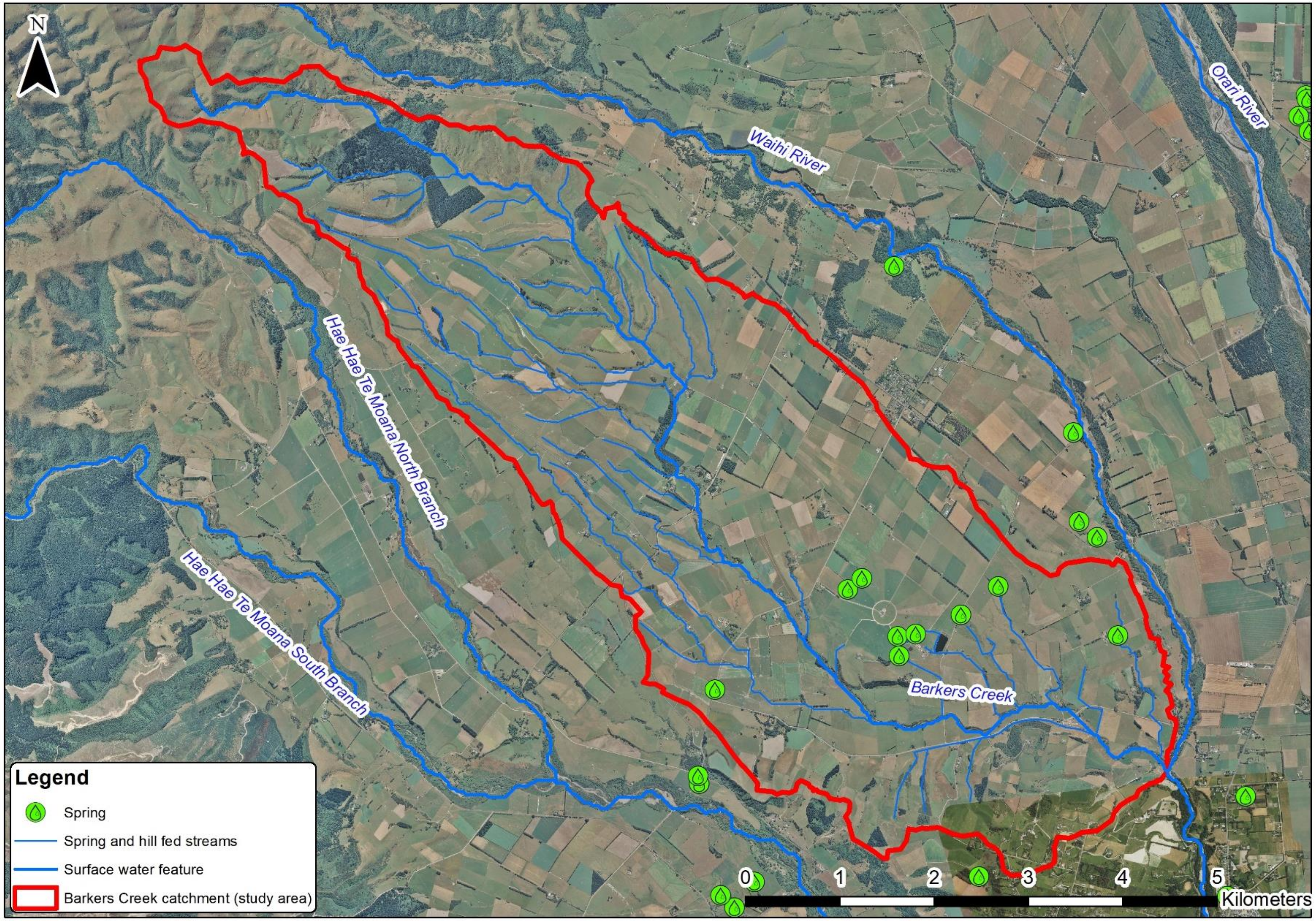

Figure 3-8: Surface water features and springs in and around the Barkers Creek catchment

Surface water use within this catchment is for permitted use (i.e. stockwater) and irrigation. Permitted use of surface water allows for 10 m^3 at no more than 5 l/s to be taken per day. Consents are required to take surface water in excess of the permitted use volumes. There are currently no issued consents to take water from the main stem of Barkers Creek. However, there is one consent issued to take water from a spring-fed tributary. Water can be taken between October and April from three abstraction points for a combined rate of 25 l/s. This water is pumped into a storage pond where is it then used for irrigation.

Between Environment Canterbury's Springs Database and the work of this study, nine springs have been identified across the catchment[2]. A spring is a point or area where groundwater discharges to the surface. The identified springs are all in the lower Barkers Creek catchment, where it is thought groundwater is upwelling. Burbery and Ritson (2010) proposed this area to be a zone of groundwater convergence, influenced by the basalt extrusion of the Geraldine Downs. Figure 3-8 shows the location of mapped springs in the Barkers Creek catchment.

3.8 Groundwater

In Barkers Creek and much of Canterbury, aquifers are found in Quaternary alluvial gravel deposits which occur across the plains, basins and valleys. The gravels have been eroded from mountains, transported by rivers, deposited and in places reworked, with varying amounts of finer matrix material (sand, silt and clay) filling the pore spaces. The main water-bearing zones in these alluvial aquifers typically occur in 'free' gravels

[2] While only nine have been mapped, there are likely more located through the Barkers Creek catchment.

and sandy gravels, whereas silty to clayey gravels tend to constrain groundwater movement. Water-bearing zones may occur in discrete lenses or channels of cleaner gravel within otherwise silty or clayey gravel deposits (Davey, 2006). Preferential flow channels within the gravels and geological faulting can influence groundwater flow.

There has been limited groundwater exploration in the catchment with only 20 bores having been drilled, several which were unsuccessful in finding groundwater yields sufficient for the required use (primarily stockwater). The primary water bearing formations in the Barkers Creek catchment are thought to include recent to Quaternary age alluvium and the Kowai formation based on these bore logs (examples in Appendix A). Based on the available borelogs, Figure 3-9 shows a typical gravel exposure observed along the banks of Barkers Creek. The gravels in the photo reflect the tight claybound nature of the gravels that groundwater is sourced from in the catchment.

Figure 3-9: Photo of Barkers Creek bank gravel exposure

Within the Barkers Creek catchment groundwater is used for domestic and stockwater supply only (i.e. permitted volume use of up to 10 m^3 per day at less than 5 l/s).

4 Methodology

4.1 Research approach

The research strategy for this study was split two parts:

1. Data collection, and
2. Analysis and interpretation of those data to answer the research aims and objectives presented in Section 1.2.

4.1.1 Part 1: Field investigation strategy

An integrated investigative strategy was used that examined both surface water and groundwater both in terms of hydrological and hydrochemical properties. Field data collection was carried out over a 12 month period, between September 2016 and August 2017.

Part 1 of the research strategy for this study had three stages that each constitute a different temporal resolution;

1. An initial, broad, catchment-wide site survey to characterise general hydrochemistry and map its geospatial distribution. This involved spot measurement of a water chemistry and a piezometric survey. The results from this initial survey informed the design of the monitoring during stages 2 and 3;
2. To evaluate differences in loads of key contaminants of concern (nitrogen and phosphorus), low frequency bimonthly monitoring was undertaken. This involved spot flow-gauging and concurrent water quality measurement concentrated in the lower Barkers Creek catchment (i.e. downstream of McKeown Road);

3. High frequency (automated) monitoring of surface water flows and groundwater levels at select sites in addition to monitoring several storm flow events. Fortnightly monitoring of nitrogen and phosphorus in surface water at a subset of sites from component two. These sites were limited to the main stem of Barkers Creek and the Waihi River above the confluence with Barkers Creek.

Broad-scale catchment-wide survey (Stage 1)

i. A one-off qualitative field-mapping exercise was undertaken in late August 2016. The purpose of this was to locate all surface water/spring inputs into Barkers Creek and to identify appropriate surface flow and water quality sampling locations. Efforts were concentrated on the lower Barkers Creek catchment, downstream of McKeown Road bridge;

ii. To evaluate hydraulic gradients and map groundwater flow directions a piezometric survey was undertaken in September 2016. To ensure monitoring site suitability potential sites were visited as a QA/QC assessment prior to the survey. To help understand the relationship between surface water and groundwater concurrent flow gauging were also undertaken on Barkers Creek at high spatial resolution below McKeown Bridge during the piezometric survey. In addition, direct measurement of discharges from major tributaries (identified in i) downstream of McKeown Road bridge were also undertaken;

iii. To enable hydrochemical characterisation of groundwater and surface water in Barkers Creek a catchment-wide surface water and groundwater sampling run was conducted. In addition to nitrogen and phosphorus, general water chemistry was also analysed. Surface water quality samples were taken at 20 sites coincident with flow gauging measurements during the piezometric survey.

Bores able to be sampled for groundwater (identified during ii) also had samples collected (20 sites).

Low frequency monitoring (Stage 2)

iv. To understand how nitrogen and phosphorus concentrations and loads vary during the monitoring period, bimonthly concurrent flow gauging was conducted in conjunction with water quality sampling at 19 surface water sampling sites and five groundwater monitoring bores distributed across the catchment. The surface water and groundwater chemistry analytical suite covered nitrogen species, phosphorus and TSS (in surface water only), in addition to standard field parameters of pH, temperature, dissolved oxygen and conductivity.

High frequency monitoring (Stage 3)

v. To establish groundwater level and surface flow trends along with relationships between surface water, groundwater and rainfall in the catchment, continuous monitoring of groundwater levels and surface flow was undertaken. Down-hole automated loggers were used and installed at four existing bore locations, spread across the catchment and at varying screened intervals. Continuous flow monitoring was undertaken at two flow recorder sites on the lower reaches of Barkers Creek (McKeown Road bridge and Sercombe Road bridge);

vi. Fortnightly monitoring of nutrients (nitrogen species, phosphorus species) and TSS at four sites along Barkers Creek between the McKeown Road Bridge and the confluence with the Waihi River and at one site on the Waihi River upstream of the Barkers Creek confluence;

vii. To understand how nutrient and sediment concentrations and loads vary during storm events and compare to baseflow conditions storm sampling was undertaken. Samples were taken at different time points spanning the rising and falling limb of the hydrograph. Operation of two automated water sampling units placed on Barkers Creek, one towards the bottom of the catchment at Sercombe Road Bridge and the other at McKeown Road Bridge. Three storm flow events were targeted, of varying rainfall intensity and duration with the intention of being spread across different seasons. Water sample collection was automatically triggered by a predetermined flow trigger level. Samples were analysed for nitrogen species, phosphorus and TSS.

4.1.2 Part 2: Analysis and interpretation

Part 2 of the research strategy was the analysis and interpretation of the data collected in Part 1. Water chemistry data from the initial broad-scale site characterisation was interpreted using water chemistry, graphical and Geographic Information System (GIS) mapping methods. This informed whether any geospatial pattern of water-type/quality was identifiable across the catchment. Groundwater flow paths along with horizontal and vertical gradients were determined from the results of the piezometric survey.

The low frequency (bimonthly) monitoring data was used to construct a mass balance model for Barkers Creek. This allowed nutrient and sediment pollution hot spots to be identified, and key transfer pathways to be identified. Normalisation of the flow gauging results yielded an estimate of how much groundwater discharges to Barkers Creek through direct discharge/seepage to its stream bed, versus point discharges via spring-fed streams. Mass fluxes of nitrogen and phosphorus were calculated from the flow and concentration data collected and an assessment made of how these loads relate to loads measured in the Waihi River upstream of Barkers Creek.

The high frequency measurement of flows, groundwater levels nitrate, phosphorus and TSS provided an understanding of the relationships between concentrations and loads during storm flows vs baseflow conditions. Further, it will identify whether storm flows are a dominant export pathway for nutrients and sediment from Barkers Creek to the Waihi River.

4.2 Sampling methods and data collection

4.2.1 Groundwater level measurement

To get the best understanding of groundwater level patterns in the lower Barkers Creek catchment, four bores had groundwater level recorders installed (Figure 4-1). Where possible bores chosen for groundwater level monitoring had no pump installed to eliminate self-induced pumping interference and provide a complete data record. Static groundwater levels were also collected when groundwater quality samples were taken. The static groundwater levels were measured through a bore head access point, usually at the top of the bore casing.

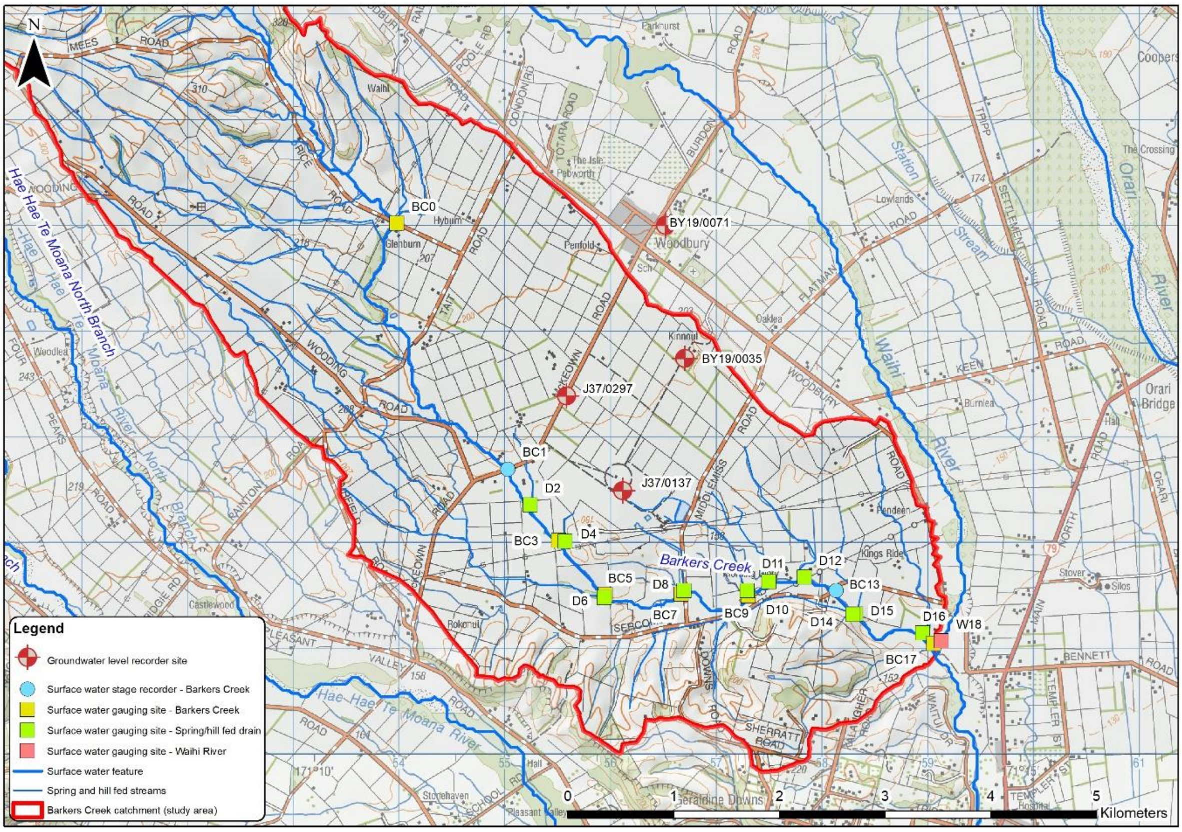

Figure 4-1: Location of surface water flow and stage monitoring sites and groundwater level recorder sites

Groundwater levels were measured using the procedures outlined in 'National Environmental Monitoring Standards - Water level' (Ministry for the Environment, 2016). Groundwater level measurements using either a Seametrics LevelSCOUT Water Level Logger (automated groundwater level recorder sites) or a Solinst 101 Water Level Meter (for manual groundwater level measurements).

4.2.2 Surface water stage and flow

Locations at which surface water was monitored in Barkers Creek were first identified through a walk down the reach from McKeown Road to the confluence with the Waihi River. All spring and hill-fed tributaries that flow outside of storm events along this reach were also identified as being suitable for surface water flow to be measured. To get the best understanding of surface water flow in the lower Barkers Creek catchment, 19 surface water flow gauging sites had surface water flow measurements collected bimonthly. Two of these sites also had surface water stage recorders installed (Figure 4-1).

Surface water flow gaugings were undertaken in accordance with the procedures outlined in 'National Environmental Monitoring Standards - Open channel flow measurement' (Ministry for the Environment, 2013). Flow measurements were made primarily using a SonTek Flowtracker Acoustic Doppler Velocimeter. Some sites required a visual flow assessment to be made due to flows being too low (1-2 l/s) or the site being too narrow. Visual flow assessments were limited to the spring and hill-fed drains feeding into Barkers Creek.

Surface water stage monitoring were undertaken using the procedures outlined in 'National Environmental Monitoring Standards – Water level' (Ministry for the Environment, 2016). Surface water stage measurements were made at 5 minute intervals using a Teledyne ISCO 1640 Liquid Level Actuator.

4.2.3 Piezometric survey

A piezometric survey is a survey of groundwater levels (and in some instances surface water stage and flow) across an area at a single point in time (i.e. on the same day). The piezometric data collected can then be used to create maps of piezometric surfaces which assist in the understanding of aquifer recharge and discharge areas, groundwater flow directions and horizontal and vertical hydraulic gradients.

Method

During late August 2016, field inspections were undertaken to identify bores suitable for inclusion in a piezometric survey. During the field inspections, various details were collected including, bore depth and access at the bore head to enable groundwater level collection. Figure 4-2 shows the locations of the bores and surface water flow gauging sites used in the piezometric survey.

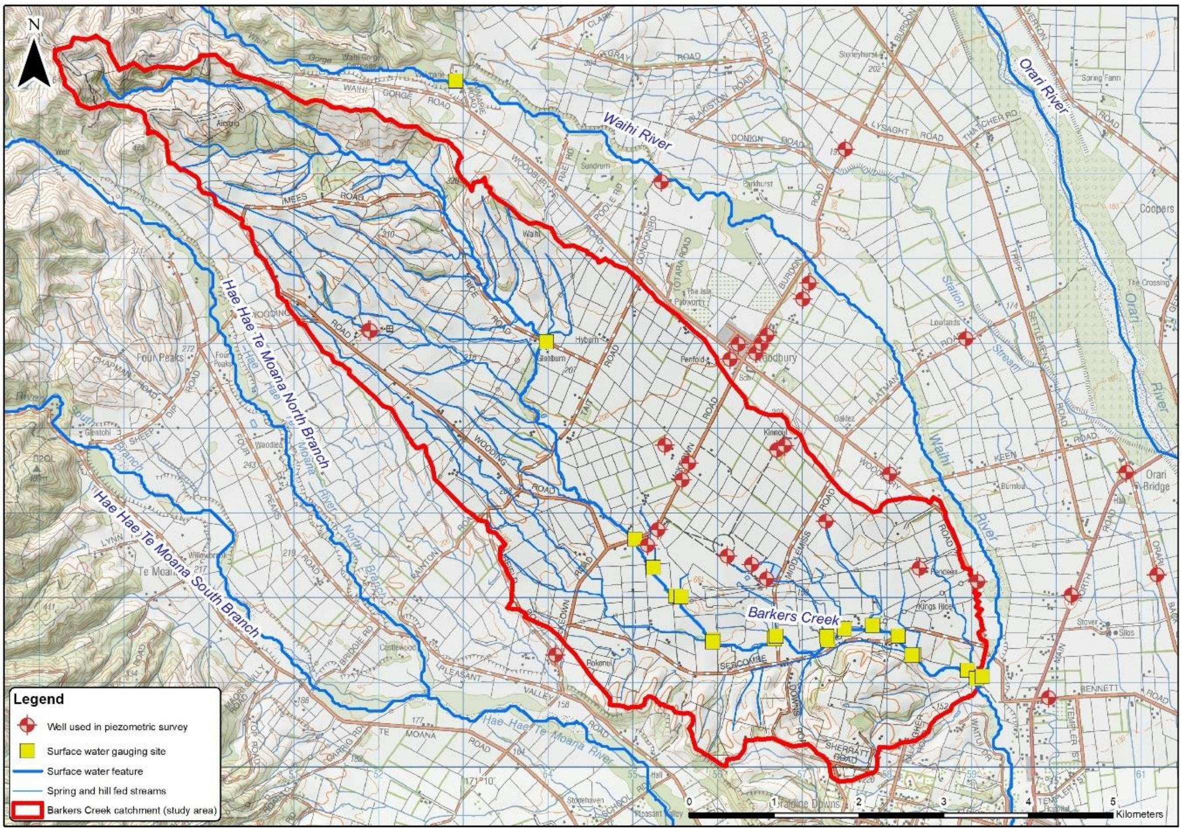

Figure 4-2: Map showing the location of bores and surface water flow gauging sites used in the piezometric survey

Groundwater level were surveyed on 1 September 2016. The 38 measurements were all taken within a 12 hour period. Surface water flow were concurrently measured at 20 sites. The bores used in the survey constitute all known bores with groundwater level access between the Waihi River and the Hae Hae Te Moana North Branch. There are minimal bores inland of McKeown Road which limits the usefulness of the piezometric surface inland of McKeown Road.

Survey conditions

An Environment Canterbury rainfall station (410111 – Woodbury) was used to obtain rainfall records for the Barkers Creek catchment for the period leading up to, and following, the piezometric survey. A daily record for this site is shown in Figure 4-3. There was little rainfall in the weeks leading up to the piezometric survey, thus rainfall interference on groundwater levels and river flows was minimal.

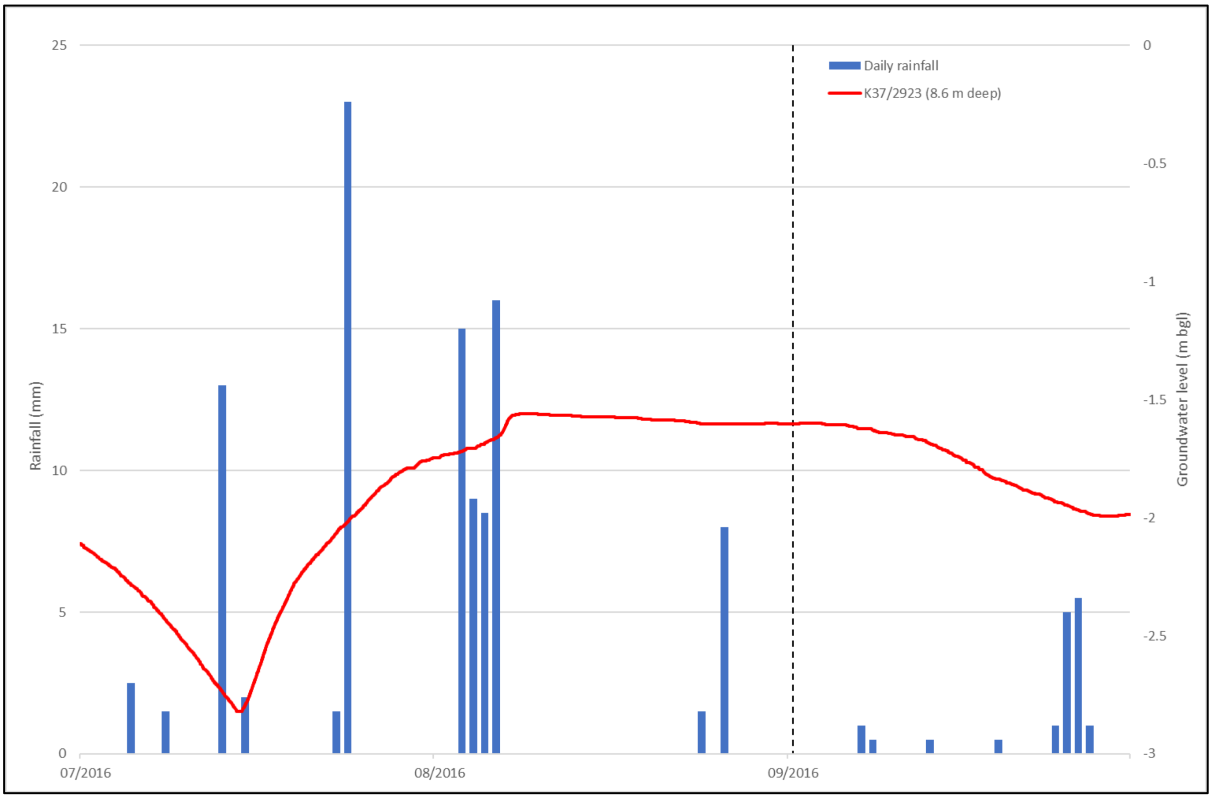

Figure 4-3: Daily rainfall and groundwater level conditions for the period leading up to, and following, the piezometric survey. Vertical black dashed line marks day of piezometric survey

The purpose of the piezometric survey at the end of winter was to reduce the potential for localised errors to be introduced into the dataset from abstractions. Despite this, it should also be pointed out that the groundwater system is dynamic and at any time of the year groundwater levels will be affected by cumulative effects of pumping and other recharge mechanisms (i.e. river losses, climate conditions etc.).

At the time of this survey, groundwater level monitoring for this study had only just begun. As such, a groundwater level recorder site run by Environment Canterbury has been used to assess groundwater level conditions in the Barkers Creek catchment at the time of the piezometric survey. Based on the groundwater level hydrograph in K37/2923 (Figure 4-3), groundwater levels appear to be at a stable level, albeit elevated due to rainfall in July and early August 2016.

Figure 4-4 shows flow in the Waihi River before, during and after the piezometric survey. Like groundwater levels, a site run by Environment Canterbury was used as the flow recorders installed for this study had minimal data to assess baseflow conditions. At the time of the piezometric survey, surface flow were nearing baseflow conditions, so measured changes in flows along Barkers Creek was considered indicative of groundwater gains and losses.

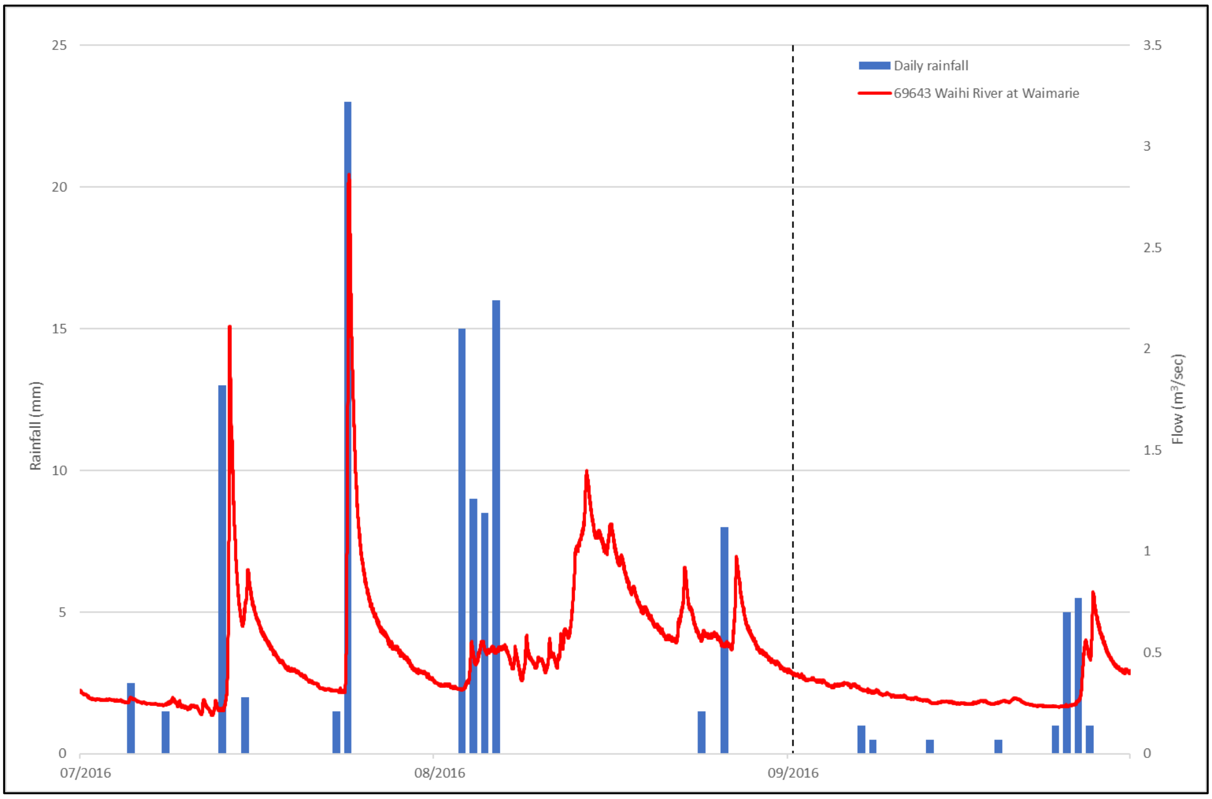

Figure 4-4: Surface water flow conditions for the period leading up to, and following, the piezometric survey. Vertical black dashed line marks day of piezometric survey

4.2.4 Groundwater quality sampling

Broadscale groundwater sampling occurred at 20 sites between the Waihi River and the north branch of Hae Hae Te Moana River (Figure 4-5). The purpose of the broadscale groundwater quality survey was to characterise general hydrogeochemistry and map its geospatial distribution, helping to establish a conceptual understanding of the catchment. In addition to this sampling, groundwater sampling was carried out on a bimonthly basis at five sites across the Barkers Creek catchment (Figure 4-6). Bimonthly sampling was undertaken to assess annual variations in nitrogen and phosphorus in the catchment.

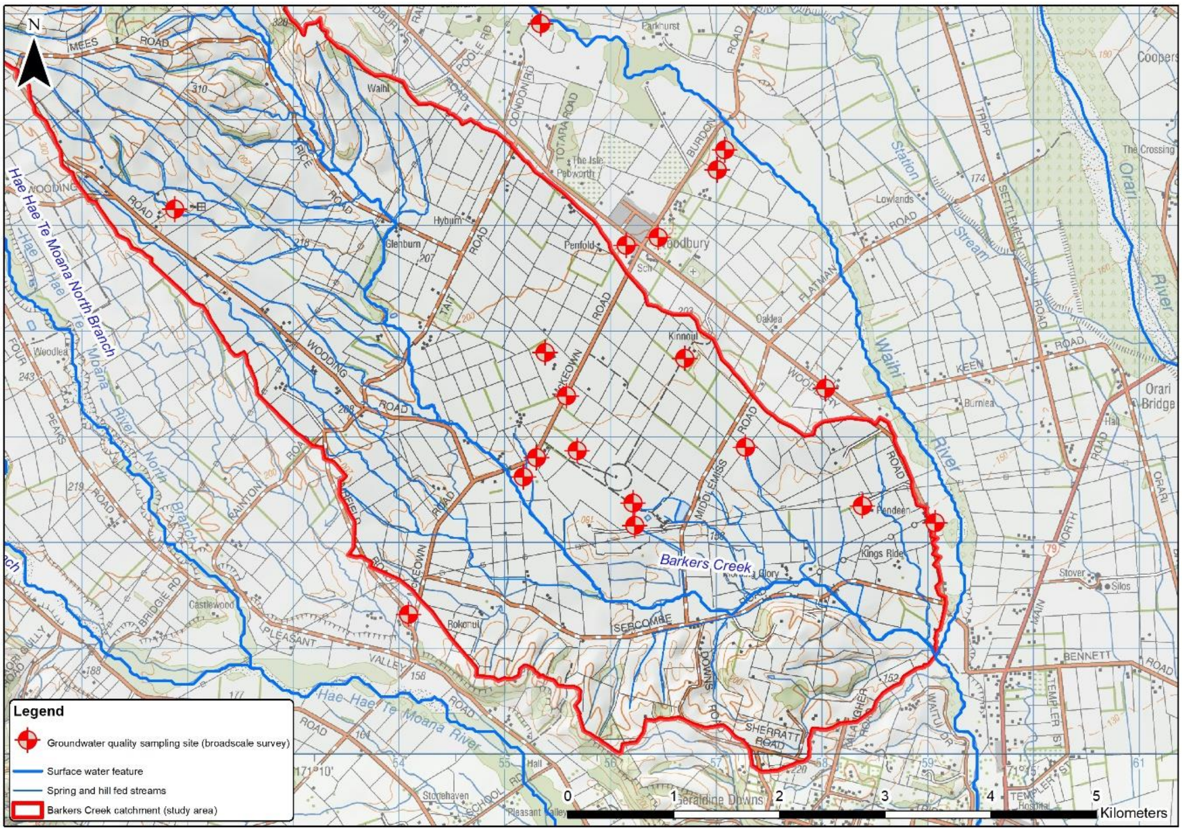

Figure 4-5: Broadscale survey groundwater quality sampling sites

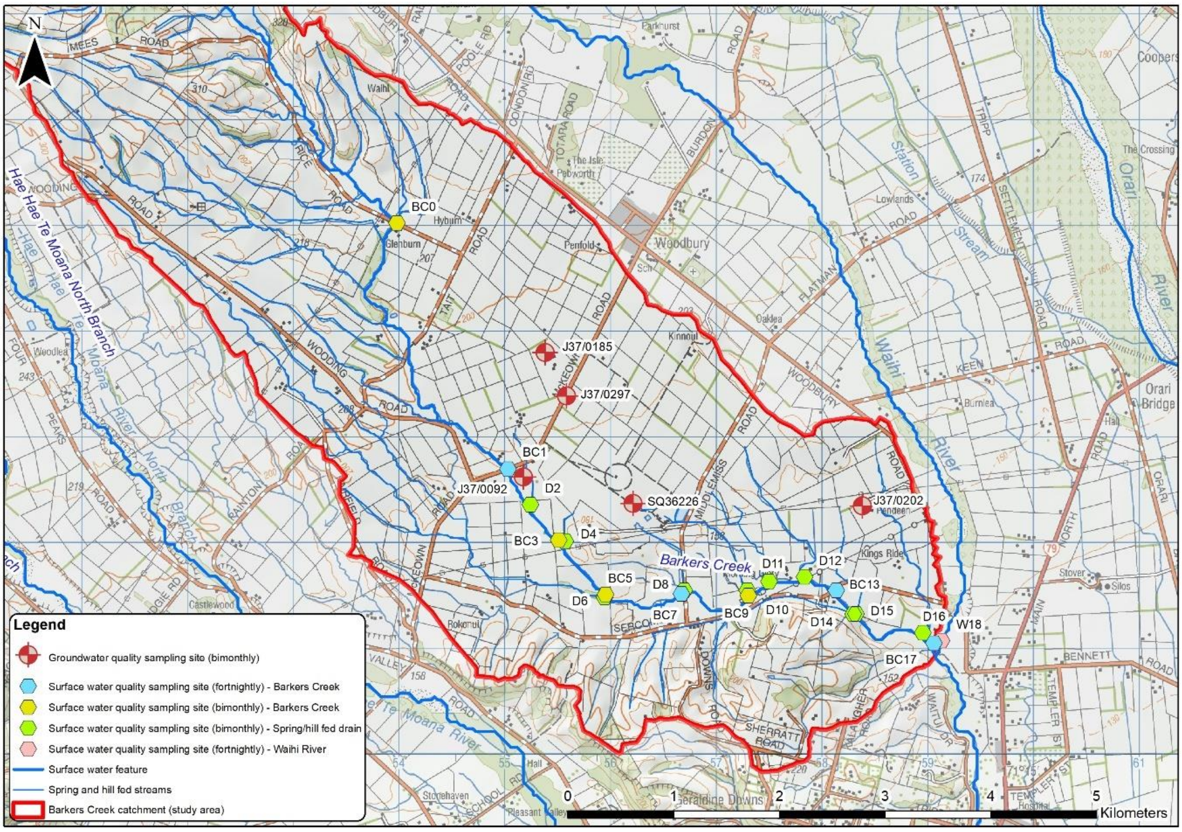

Figure 4-6: Surface water and groundwater quality sampling locations

Groundwater samples were collected as per the procedures outlined in 'A national protocol for state of the environment groundwater sampling in New Zealand' (Ministry for the Environment, 2006). Like the surface water quality samples, following collection samples were chilled for transport to the laboratory for analysis.

4.2.5 Surface water quality sampling

Surface water quality sampling locations were identified through preliminary site investigations[3] to assess potential nutrient and sediment tributary input to Barkers Creek during a 12 month period. At each location the field parameters pH, conductivity, dissolved oxygen and temperature were measured instream with a YSI Professional Plus Multiparameter Instrument. Surface water samples were then collected in sample bottles and immediately chilled for transport to the laboratory for analysis. As there were no national surface water quality sampling guidelines at the time of the sampling, collection occurred in line with the 'Procedures Manual: Surface water quality and ecosystem health' produced by Environment Canterbury (2015).

Depending on the site, samples were collected either as a one-off, fortnightly or bimonthly (see Figure 4-6) between September 2016 and August 2017. This provided a total of six sampling events at 19 sites and 26 sampling events at five sites. Analytical suites for one-off, bimonthly and fortnightly sampling events are presented in Appendix B.

[3] A stream walk from McKeown Road bridge to the confluence with the Waihi River which occurred in August 2016.

4.2.6 Storm flow event sampling

Three rainfall events were targeted for intensive monitoring in the Barkers Creek catchment during the data collection stage of this study. Surface water samples were collected with Teledyne ISCO 6712 Portable Samplers, installed at the two surface water stage recorder sites (Figure 4-7). Surface water sample spacing was programmed based on predicted rainfall with the goal of samples being taken across the rising and falling limbs of the hydrograph. 24 samples were programmed to be taken for each of the rainfall events, with 10 samples from each site sent to the laboratory for analysis of nutrients (nitrogen and phosphorus species) and TSS.

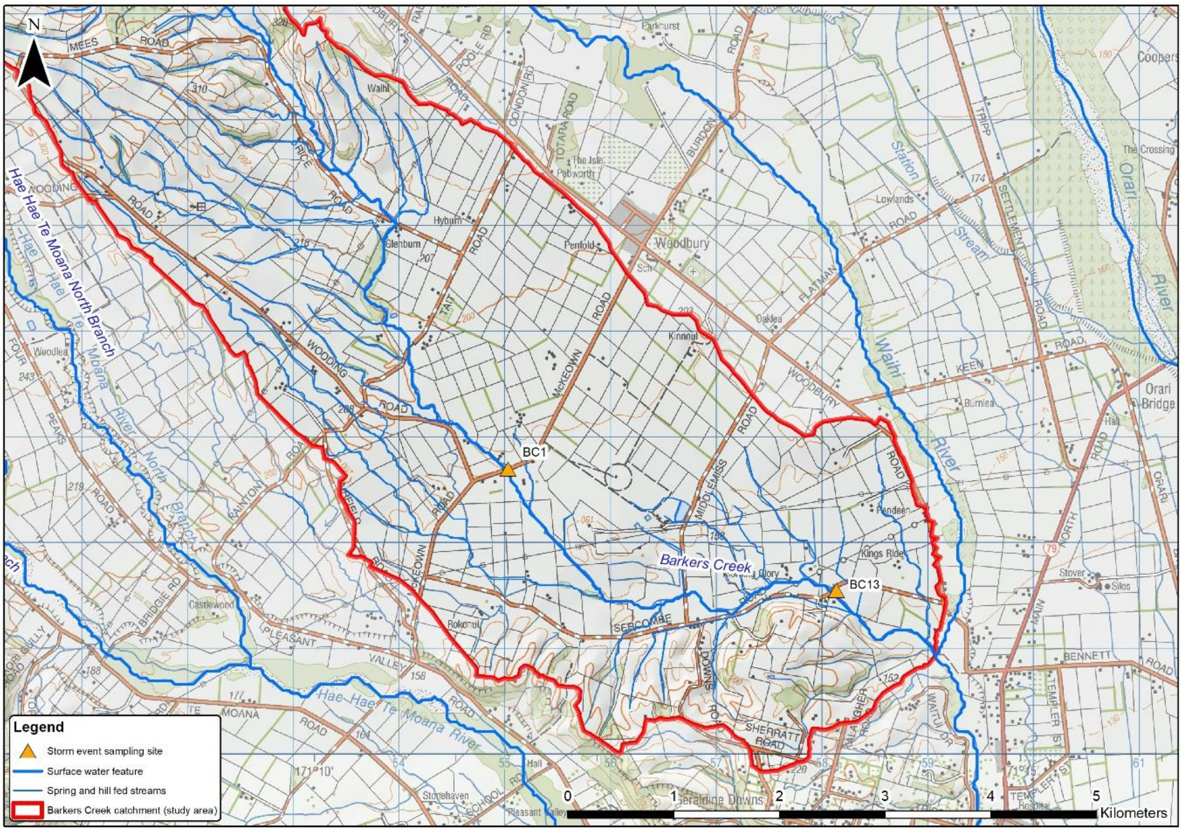

Figure 4-7: Storm event sampling monitoring sites

4.2.7 Laboratory analysis

All groundwater and surface water samples were delivered to Hill Laboratories in Christchurch for chemical analysis. Samples were delivered the same day they were collected except for the autosampler samples from storm events. In some cases it took up to three days between storm event sample collection and delivery to the laboratory. During setup for the storm flow sampling event ice was placed within the auto-sampling unit to keep samples cool until such time they could be delivered to the laboratory. Specific parameters for both the broadscale and higher frequency monitoring, along with the laboratory analysis method used are set out in Appendix B

4.3 Data processing and analysis

4.3.1 Piezometric contour mapping

To allow groundwater levels to be directly comparable, the levels collected were converted to elevations in metres above mean sea level (m msl). Groundwater elevations were calculated by subtracting the measured ground level from the land surface elevation. Elevations were acquired from LiDAR, 10 m DEM and, where available, bore specific survey data. Locations where all three data sources where present could be compared to understand the accuracy of the 10 m DEM. While LiDAR (accuracy of ± 0.15 m) and surveying (accuracy of ± 0.1 m) have a high degree of accuracy, there is less certainty as to the elevations produced by 10 m DEM. Six of the 31 bores used in the piezometric survey with elevations from each of the data sources had ranges of between 0.07 and 0.37 m. This gives some assurances that the elevations from the 10 m DEM (required for 7 of the 31 bores used in the piezometric survey) are suitable for the production of the piezometric contour set for this study.

Piezometric contour mapping involved the creation of a number of trial piezometric maps using different combinations of groundwater level data measured in the September 2016 survey, together with other data (e.g. spring head elevations, surface water stage elevations). To produce a robust set of piezometric contours the following combinations of data were trialled:

- groundwater head elevations from all of the bores
- groundwater head elevations from shallow bores less than 40 m
- combinations of groundwater head elevations and stage height elevations from surface water features
- combinations of groundwater head elevations and spring head elevations using know perennial spring locations
- combinations of groundwater head elevations, stage height elevations and spring head elevations.

The results of the trial piezometric maps were used to inform the understanding of the hydrological system and to generate the final interpreted piezometric map. Stage height and spring head elevations have been used only to inform interpretations, but haven't been included as pseudo groundwater levels when creating the final piezometric map.

Piezometric contours were generated by subtracting the measured depth to groundwater from the elevation of measuring points (i.e. to obtain the hydraulic head relative to mean sea level). These data were then contoured with Surfer 8 software using kriging. The contours set produced were then interpreted and edited manually to produce a representative piezometric contour set for the Barkers Creek catchment.

4.3.2 Vertical gradients

Comparing groundwater levels between deeper and shallower bores can help to understand whether groundwater is flowing upwards or downwards through the aquifer system. This affects aquifer vulnerability to contamination (where a downwards vertical gradient would indicate a higher vulnerability to contamination), transport pathways and groundwater recharge and discharge mechanisms.

The vertical head differences were converted to vertical gradients using bore pairs by subtracting the hydraulic head elevation in the shallower bore from the hydraulic head elevation in the deeper bore, and dividing the remainder by the absolute value of the vertical distance (using elevations) between the representative bore depths[4] (Price, 1996). Elevations above mean sea level (m msl) has been used in all cases when performing these estimations.

If the head in the shallow bore is higher than the head in the deep bore, the resulting value is negative and this indicates a potential downward vertical hydraulic gradient and groundwater is assumed to flow from the shallow water-bearing formation downwards. This indicates a possible recharge area setting. Conversely, if the head in the shallow bore is lower than the head in the deep bore, the resulting value is positive, and indicates a potential upward hydraulic gradient and groundwater is assumed to flow from the deep water-bearing formation upwards. This indicates a possible

[4] The representative bore depth was calculated to be the middle of the uppermost bore screen, or 1.5 m (assumes a 3 m screen length) above the bore depth where there was no screen information. In cases where the bore was less than 3 m deep the bore depth was used.

discharge area setting. The magnitude of the vertical gradient and the vertical hydraulic conductivity of the aquifer material will be controlling factors of the degree of interaction between water-bearing zones. A large vertical hydraulic gradient does not mean more recharge if the vertical hydraulic conductivity is low.

4.3.3 Hydrochemistry

Water chemistry data were processed and analysed using Aquachem-QA water quality software. Aquachem was used to convert solute data from milligrams per litre (mg/L) into milliequivalents per kilogram (meq/kg) for ease of comparative analysis When comparing water quality samples, it can be difficult to compare a large number of chemical parameters for each sample simultaneously. In order to easily compare the relative major ion concentrations of the surface water and groundwater data, were plotted on stiff and piper diagrams.

Stiff diagrams use four parallel, horizontal axes extending either side of a vertical axis representing zero. Concentrations of four anions and four cations are plotted either side of this vertical axis in meq/l. The shape and size of the resulting polygon is indicative of the ionic composition of the water (Hounslow, 1995). The relative size of the Stiff diagram provides a measure of the total ion content of the water sample with different ionic compositions indicating geological influences and/or different recharge sources. In cases where the recharge water chemistry is the same and geology is uniform, the relative amount of dissolved ions can also provide a proxy for groundwater age. This is because groundwater will have more dissolved minerals when it has been in contact with aquifer materials for longer.

Piper diagrams are also a useful graphical aid for examining water. A piper diagram displays the ratios of the major cations (calcium, magnesium and sodium plus potassium) and anions (sulphate, chloride and bicarbonate plus hydrogen carbonate) of an analysis on two separate ternary (triangle) plots. The cation and anion ratios in each ternary plot are then projected onto a diamond. The position of a sample in the diamond part of the piper diagram can be used to make an assessment on the origin of the water (Hounslow, 1995; Piper, 1944). This analysis allows surface water and groundwater of various major ion compositions to be distinguished by their position on the diagram (Piper, 1944).

Under low, or no, dissolved oxygen conditions, elements such as iron and manganese can become dissolved in water, increasing their concentrations. Other compounds such as nitrate-nitrogen have low concentration because microorganisms convert them to other nitrogen species, a process known as denitrification (see Section 2.1). Denitrification is a key removal process for nitrate-nitrogen (Burgin & Hamilton, 2007; Rivett et al., 2008). Most groundwater in Canterbury is oxic, and denitrification is not likely to be occurring. However, where water is anoxic denitrification can occur, reducing the concentration of nitrate-nitrogen in the groundwater. The methodology used to assign a redox state for each sampling location follows that used by McMahon and Chapelle (2008). High dissolved oxygen and nitrate-nitrogen and low manganese concentrations indicated oxic groundwater conditions, and the opposite for anoxic conditions. Sites can also have a 'mixed' redox state which suggests that the groundwater system is not in redox equilibrium.

Hierarchical cluster analysis (HCA) is a statistical technique for analysing large, multivariate datasets, such as water quality data, where data is available from a number of different parameters. Data are sorted into clusters where, in this case, the water quality data from sampling sites in the same cluster is more similar to each other compared to those in other clusters. HCA builds a hierarchy of clusters, where the highest cluster represents all the data and the lowest clusters represent individual bores. The cluster analysis undertaken for this study assumes all sites start in their own cluster, and pairs of clusters are merged recursively to generate the hierarchy (agglomerative clustering). The linkages between each cluster are based on the Ward variance minimisation algorithm, using water quality data for 20 surface water and 20 groundwater quality sites, and 16 different water quality parameters. Analysis was undertaken using the Cluster Analysis tool in Statistica.

4.3.4 Flow gauging

Surface water gains and losses to groundwater along Barkers Creek were calculated using differential gauging with concurrent gauging data. Surface water gains and losses were calculated for each Barkers Creek site by removing flow from the upstream Barkers creek site and tributary inputs creating a naturalised flow using the following equation:

$$Surface\ water\ \frac{gain}{loss} = Flow_{site} - Flow_{upstream} - Flow_{tributary\ input} \quad \textbf{Equation 2}$$

4.3.5 Stage to flow

Stage data from the McKeown Road and Sercombe Road recorder sites and manual flow gauging results were used to produce rating curves. The rating curves could then be used to construct a flow record using the Hydstra ratings package (HYRATED).

HYRATED fits a non-linear transformation between stage and gauged flow data. Rating curves for the two stage monitoring sites are presented in Appendix C

5 Results

5.1 Hydraulics

5.1.1 Piezometric contour and groundwater flow paths

Piezometric contours produced from the September 2016 piezometric survey data are presented in Figure 5-1. This was the first piezometric survey undertaken in the Barkers Creek catchment. The raw survey data can be found in Appendix D.

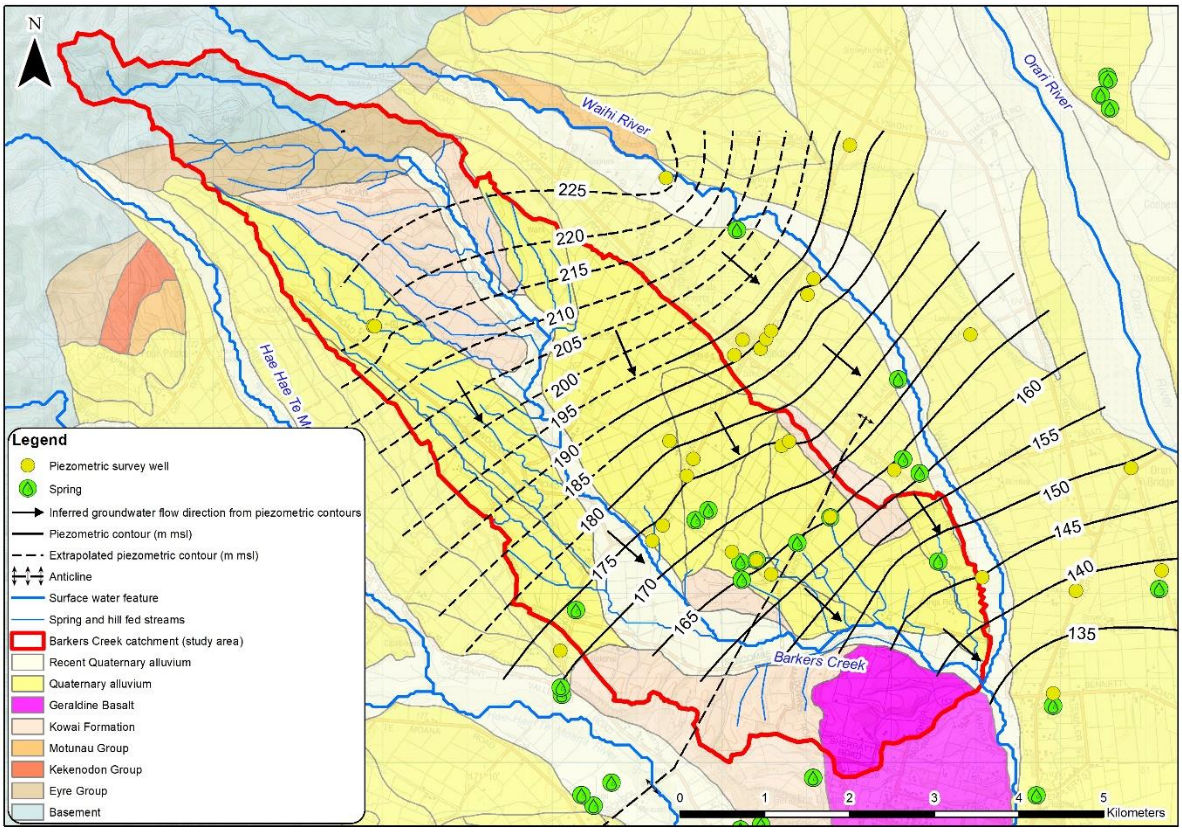

Figure 5-1: Piezometric contour map (m msl) as produced from September 2016 piezometric survey. Inferred flow direction in the Barkers Creek catchment is marked

Groundwater flow direction is perpendicular to the piezometric contours. It follows the topography of the catchment with a northwest to southeast flow direction, indicated by the arrows on Figure 5-1. The northern boundary of the Barkers Creek catchment marks an apparent groundwater divide, whereby groundwater to the north of the divide is flowing towards the Waihi River and groundwater to the south is flowing towards Barkers Creek. Towards the bottom of the catchment groundwater converges on the confluence of Barkers Creek and Waihi River. There were a limited number of bores able to be included inland of McKeown Road adding uncertainty to the piezometric contours produced in this area.

To assess vertical gradients, head difference for bores used in the September 2016 piezometric survey have been used. The vertical head differences between bores at different depth at any given location varies across the Barkers Creek catchment. Hydraulic gradients and head difference are presented in Table 5-1 and Figure 5-2.

Table 5-1: Vertical hydraulic gradients. Upwards gradients are + values and downwards gradients are - values

Bore pair	Screen[5] (m bgl)	Horizontal distance apart (m)	Head differential (m)	Calculated vertical gradient
J37/0284	35-77	23	7.21	+0.56
BY19/0013	37-52			
BY19/0091	3.7-6.7	104	-3.77	-0.33
BY19/0035	15.88-17.88			
J37/0092	5.6	220	1.25	+0.48
J37/0038	10			
J37/0298	8-13.5	351	3.50	+0.63
J37/0185	17-25			
J37/0116	1.29	306	1.30	+0.03
J37/0137	54			

[5] The representative bore depth was calculated to be the middle of the uppermost bore screen, or 1.5 m (assumes a 3 m screen length) above the bore depth where there was no screen information. In cases where the bore was less than 3 m deep the bore depth was used.

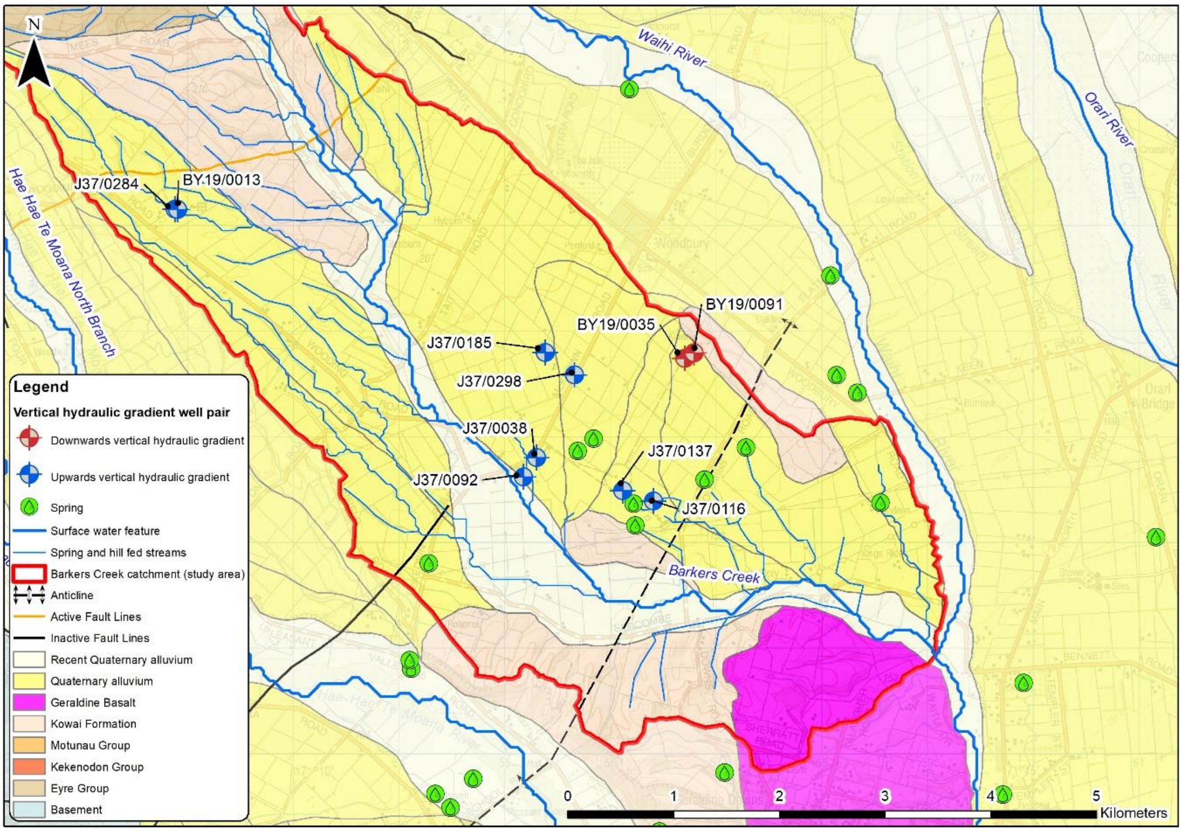

Figure 5-2: Vertical gradients bore pairs

Observations from vertical hydraulic gradient data in the Barkers Creek catchment show:

- Four of the five available bore pairs indicate upwards vertical gradients, suggesting discharge zone
- The three most downstream bore pairs with upwards gradients reflective of the observations of springs and spring fed streams discharging below McKeown Road and the zone of groundwater convergence identified by the piezometric contours
- The most upstream/inland bore pair has an upwards vertical gradient. This is likely reflecting the active faulting in the vicinity of the bore pair which could be causing upwards migration of groundwater

- A downward vertical gradient between bore pair BY19/0019 and BY19/0035. This gradient is at odds with other observational data (piezometric contours and spring locations) and suggests that the anticline and/or Kowai Formation mound are influencing groundwater flow paths in this area.

While there are no observational data to confirm, conceptually towards the top of the catchment (inland of McKeown Road) there are expected to be downward hydraulic gradients with longer, deeper groundwater flow paths expected.

5.1.2 Groundwater levels

BY19/0035 (location on Figure 4-1) had pumping interference at times during the late spring through to early autumn (October to April) creating gaps in the data record. In addition, there was a logger failure resulting in a loss of the final two months of the data record. BY19/0035 correlated strongly with J37/0297 allowing a synthetic record (see Appendix E) to be created for the study period. This allowed for general trends to be identified in the data set.

The hydrographs of the shallow bores (BY19/0035 and J37/0297, both screened in Quaternary alluvium; location on Figure 4-1) show that groundwater response to recharge events occurred in September to October 2016, mid-October 2016 to mid-December 2016, April 2017 and July to mid-August 2017 (Figure 5-3). Groundwater levels collected from these bores in general don’t indicate an immediate response to rainfall, rather a prolonged steady increase in groundwater level following rainfall over a period of weeks. During periods of less prolonged rainfall (i.e. during periods of decreasing groundwater levels) there is a steady decline in groundwater level at which point the groundwater system reaches an equilibrium. Comparing BY19/0035 and J37/0297 (both located within Barkers Creek catchment) with BY19/0071 (located in the Waihi River catchment), the responses to rainfall are slower and take longer for groundwater levels to reach equilibrium. The annual hydraulic head variation in the shallow bores was 4.0 to 6.2 m.

The groundwater level hydrograph for the deep bore (J37/0137; location on Figure 4-1) differs from the shallow bores. Unlike the shallow bores, J37/0137 is likely drilled into cover formations (see Section 3.4). Borelogs (Appendix A) suggest that these formations are fine-grained, claybound and therefore less transmissive sediments. Groundwater recharge occurred from the start of the monitoring record (September) through to mid-October, mid-November to December, April to May and mid-July to August (the end of the monitoring period). Groundwater levels in this bore had little variation across the monitoring period. The small variations are likely reflecting the clay-bound nature of the overlying 30 m of sediment. The annual hydraulic head variation in the deep bore was 1.3 m.

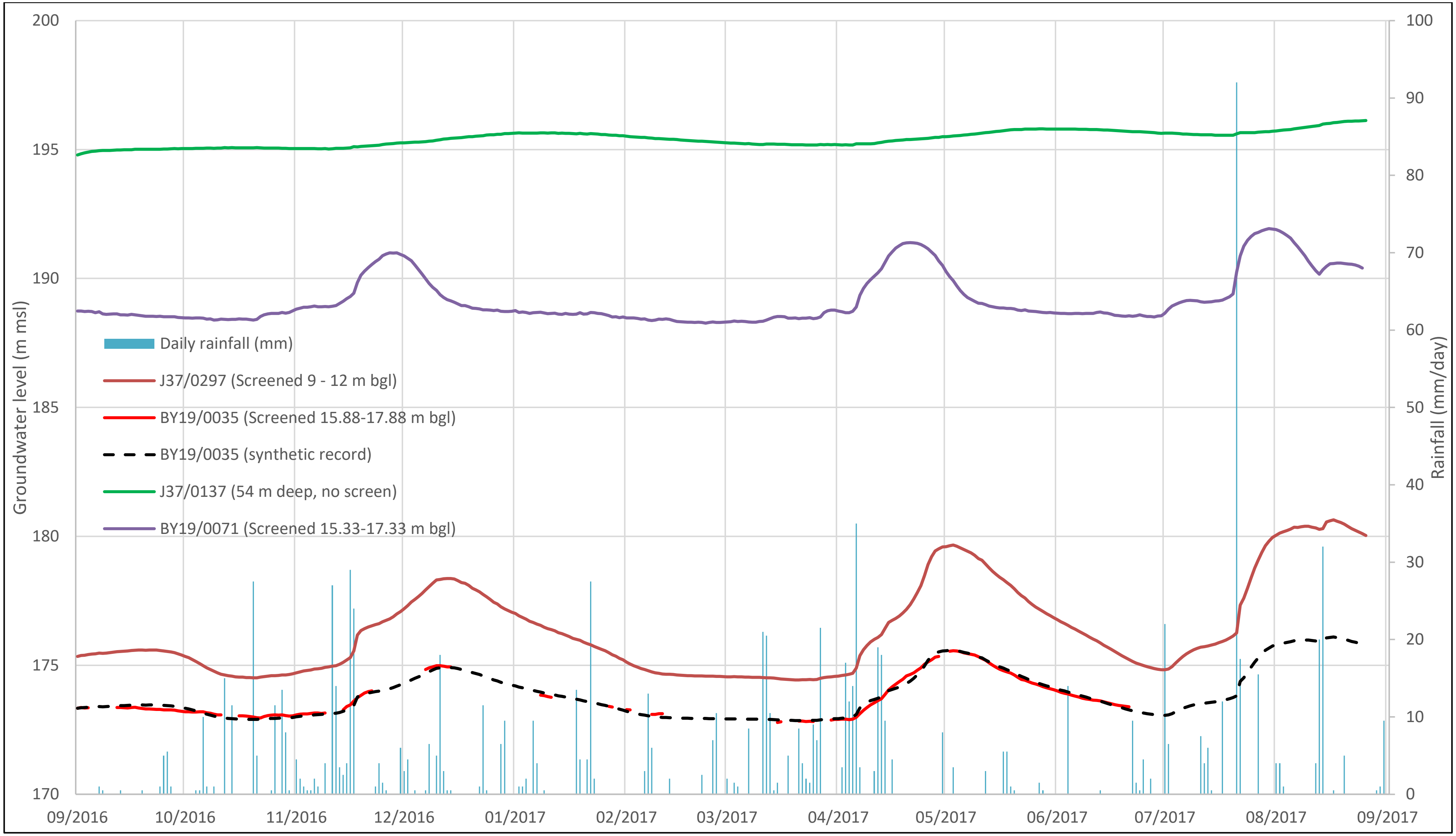

Figure 5-3: Groundwater hydrographs

5.1.3 River flows and spot gaugings

Between September 2016 and August 2017, the surface water flow in Barkers Creek was measured at two sites. Flows varied between 0.001 m^3/sec and 53.7 m^3/sec at the McKeown Road recorder site (Figure 5-4), and between 0.042 m^3/sec and 71.7 m^3/sec further downstream at the Sercombe Road recorder site (Figure 5-5). Flows rise and fall concurrently with respect to rainfall inputs. Barkers Creek at McKeown Road is upgradient of the groundwater discharge zone identified further downstream. As such during periods of dry weather, flows can get very low. An example of this was over the summer period (December – February) where cumulative rainfall was low, and flows were as low as 0.001 m^3/sec. Unlike McKeown Road, the Barkers Creek at the Sercombe Road recorder site has a number of spring-fed inputs and groundwater seepage, which keeps baseflows higher than at McKeown Road during periods of low cumulative rainfall. Figure 5-6 shows Barkers Creek under baseflow conditions at the McKeown Road (BC1) and Sercombe Road (BC13) recorder sites.

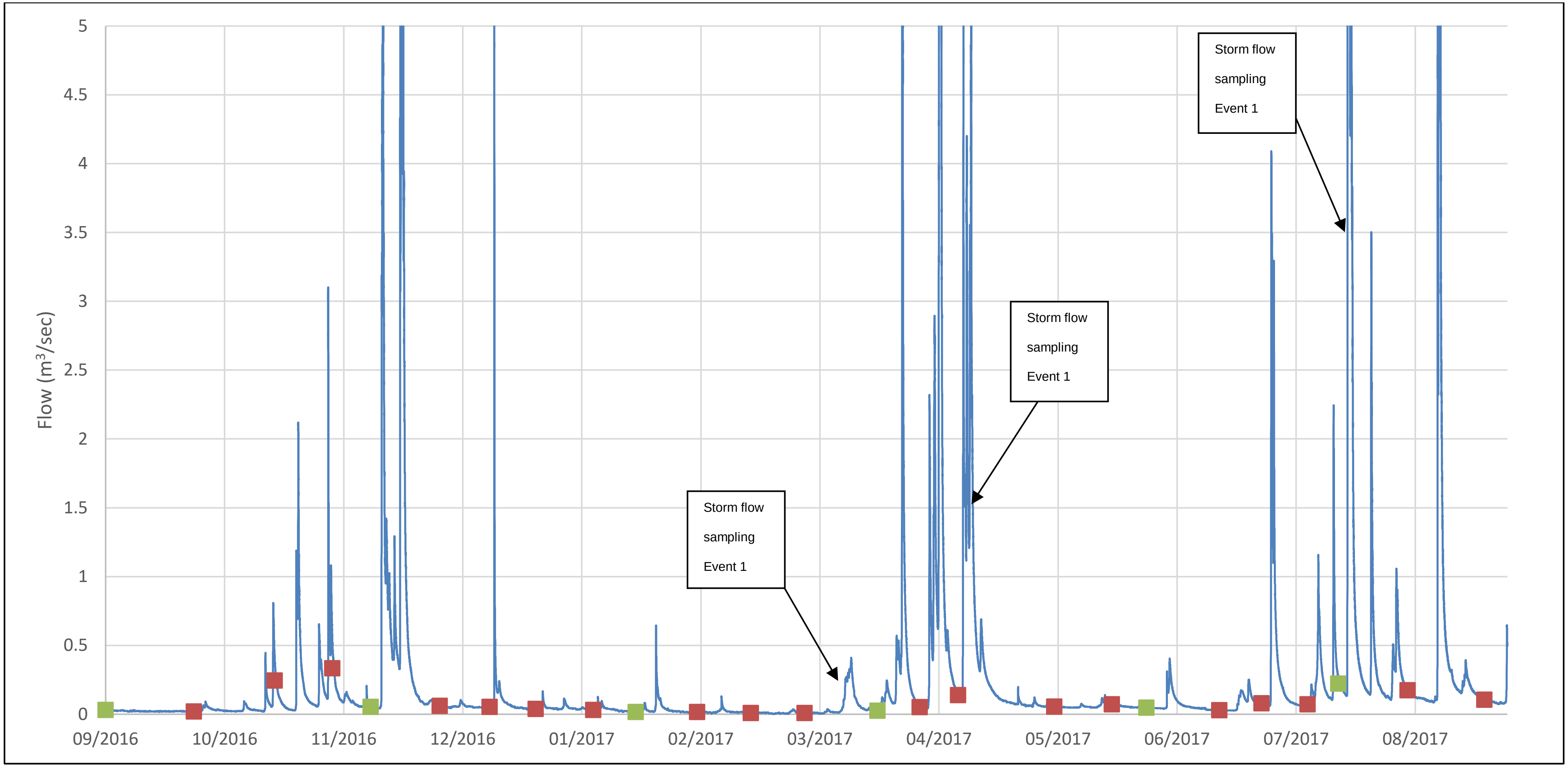

Figure 5-4: Surface water flow hydrograph for McKeown Road, Barkers Creek recorder site[6]. Green squares – bimonthly sampling, red squares – fortnightly sampling

[6] Flow on hydrograph has been constrained to 5 m^3/sec to allow for resolution of low flows. See Appendix F for full hydrograph.

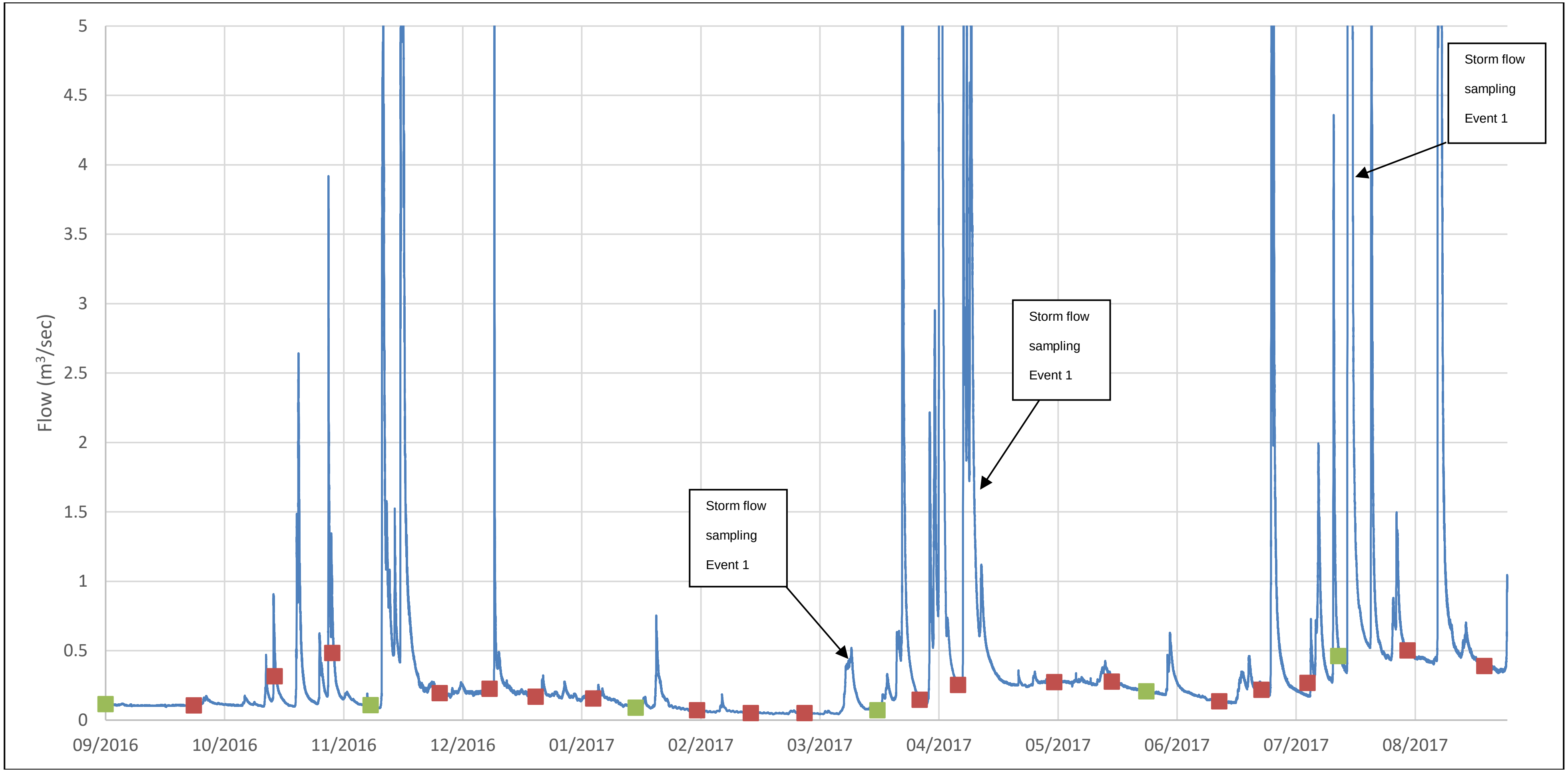

Figure 5-5: Surface water flow hydrograph for Sercombe Road, Barkers Creek recorder site[7]. Green squares – bimonthly sampling, red squares – fortnightly sampling

[7] Flow on hydrograph has been constrained to 5 m^3/sec to allow for resolution of low flows. See Appendix F for full hydrograph.

Figure 5-6: Photos of Barkers Creek during baseflow conditions. Left: Barkers Creek looking upstream at Sercombe Road Bridge. Right: Barkers Creek looking upstream at McKeown Road Bridge

Table 5-2 below presents some key flow statistics for the two recorder sites on Barkers creek. The period of record is 1 September 2016 to 31 August 2017. As expected the most downstream recorder site has higher flow statistics compared with the most upstream flow site. This is due to spring-fed drain inputs below the upstream site, and surface flow gains from groundwater.

Table 5-2: Summary flow statistics for Barkers Creek (m^3/sec)

Site	Median	Mean	7 day MALF	Q_{95}[8]	Q_5[9]	Fre-3[10]
Barkers @ McKeown Road	0.058	0.286	0.007	0.796	0.012	0.174
Barkers @ Sercombe Road	0.200	0.530	0.049	1.217	0.053	0.600

[8] The Q_{95} statistic is the flow that is exceeded 5% of the time, or the flow not exceeded 95% of the time. It is a statistic of the flood flows in the river.

[9] The Q_5 statistic is the flow that is exceeded 95% of the time, or the flow not exceeded 5% of the time. It is a statistic of the low flows in the river.

[10] The Fre-3 statistic is three times the median flow and represents a standard statistic for important fresh flows.

Spot gauging results from the bimonthly gauging runs undertaken along the main stem of Barkers Creek, along with the various spring-fed tributaries are presented in Table 5-3. With the exception of the measurements made on 19 July 2017 all spot gaugings were undertaken at or near baseflow conditions. A location map of spot gauging sites was presented in Figure 4-1)

Table 5-3: Spot gauging results for Barkers Creek and spring-fed tributaries

Site name	Site number	1/09/2016	9/11/2016	17/01/2017	21/03/2017	30/05/2017	19/07/2017
		(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)
Barkers Creek at Rice Road	2087 (BC0)	28	53	11	18	26	140
Barkers Creek at McKeown Road (recorder)	69686 (BC1)	36	55	21	24	45	226
Drain at downstream McKeown Road	1696350 (D2)	6	6	10	2*	16	14
Barkers Creek at Saywell Ford	1696345 (BC3)	46	69	30	31	61	266
Drain at downstream Saywell Ford	1696351 (D4)	3*	2*	4*	4*	5*	8*
Barkers Creek at upstream Rokonui confluence	1696346 (BC5)	47	67	32	31	63	237
Rokonui Drain at upstream Barkers confluence	1696352 (D6)	6	8	3*	2*	7	5.5
Barkers Creek at Middlemiss Road Bridge	1696347 (BC7)	58	77	37	43	74	315
Middlemiss Drain at upstream Barkers confluence	1696353 (D8)	9	9	7	5	8	16
Barkers Creek at upstream Water Race	1696348 (BC9)	59	77	36	43	79	332
Water Race at upstream Barkers confluence	1696354 (D10)	20	21	19	12	51	48
Morning Glory at upstream Barkers confluence	1696355 (D11)	8	8	17	5*	23	20
Drain at upstream Sercombe	1696356 (D12)	1*	2*	1*	0	1*	2*
Barkers Creek at Sercombe Road (recorder)	69685 (BC13)	112	125	93	68	203	437
Sercombe North Drain at upstream Barkers	1696357 (D14)	2*	1*	2*	1*	1*	2*
Sercombe South Drain at upstream Barkers	1696358 (D15)	1*	1*	0	1*	1*	3*
Drain at upstream Barkers/Waihi confluence	1696359 (D16)	2	4	1*	1*	3*	11
Barkers Creek at Waihi River confluence	1696327 (BC17)	122	133	105	82	220	495
Waihi River at upstream Barkers	1696332) W18	196	356	95	197	134	718

* = gauging made via visual assessment

5.1.4 Groundwater surface water interaction

The six concurrent gauging runs (presented in Table 5-3) undertaken for this study can be used to help understand the relationship between groundwater and surface water in the lower Barkers Creek catchment. In naturalising the flows (as described in Section 4.3.4) abstractions were assumed to be zero. This was for two reasons: 1) permitted takes (those less than 10 m^3/day) would have an insignificant impact on flows and 2) the 1 consented surface water take on the main stem of Barkers Creek was not pumping on the days of the concurrent gaugings. This was verified by visiting the location of the take several times over the concurrent gauging run. Naturalised spot gauging data for Barkers Creek is presented in Table 5-4 and Figure 5-7.

Table 5-4: Naturalised spot gaugings, Barkers Creek.

Site name	Site number	Date of gauging run					
		1/9/16	9/11/16	17/1/17	21/3/17	30/5/17	19/7/17
		l/s	l/s	l/s	l/s	l/s	l/s
Barkers Creek at McKeown Road	69686 (BC1)	36	55	21	24	45	226
Barkers Creek at Saywell Ford	1696345 (BC3)	40	63	20	29	45	252
Barkers Creek at upstream Rokonui confluence	1696346 (BC5)	38	59	18	25	42	215
Barkers Creek at Middlemiss Road Bridge	1696347 (BC7)	43	61	20	35	46	287.5
Barkers Creek at upstream Water Race	1696348 (BC9)	35	52	12	30	43	288.5
Barkers Creek at Sercombe Road	69685 (BC13)	59	69	32	38	92	323.5
Barkers Creek at Waihi River confluence	1696327 (BC17)	64	71	41	49	104	365.5

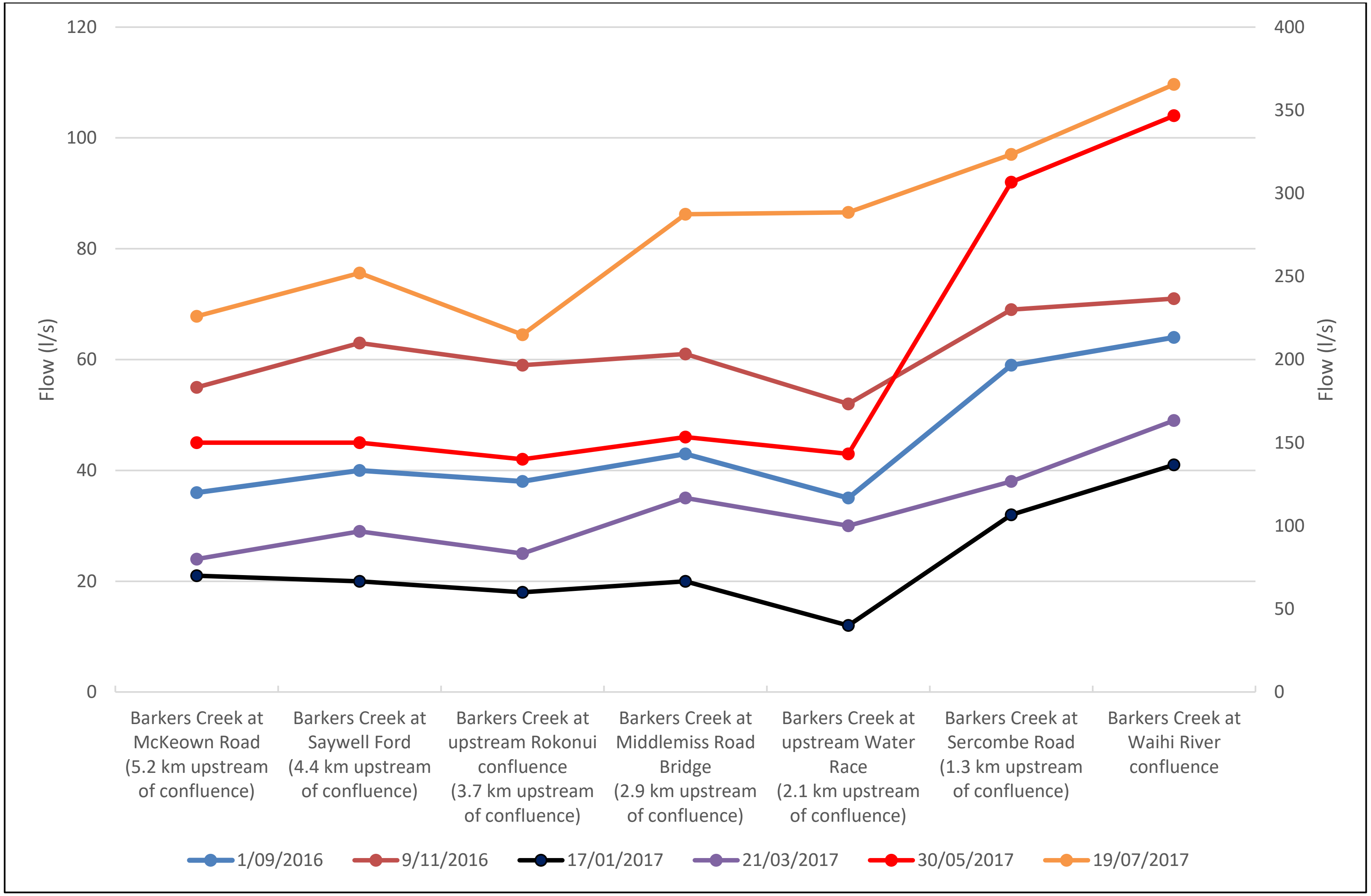

Figure 5-7: Naturalised flows in the Barkers Creek using flow data from the six concurrent gauging runs undertaken for this study.

The 19/7/2017 gauging run has been plotted on a secondary axis to allow greater resolution of all gauging runs

On average, there is a gain in flow in Barkers Creek between McKeown Road and Saywell Ford. Between the Saywell Ford and upstream of the Rokonui drain there is a loss in flow. From here, downstream to Middlemiss Road there is a gain in flow. Downstream of Middlemiss Road to upstream of the Water Race drain there is a surface water loss to groundwater. From this site there is a large gain in surface water flow from groundwater through to Barkers Creek confluence with the Waihi River. The size of these gains and losses from/to groundwater is presented in Table 5-5 and average gains/losses spatially in Figure 5-8.

Table 5-5: Gain/loss volumes. Positive numbers are a gain in surface flow from groundwater and negative numbers are a loss in surface flow to groundwater

Site name	Site number	Date of gauging run											
		1/9/2016		9/11/2016		17/1/2017		21/3/2017		30/5/2017		19/7/2017	
		l/s	% of flow	l/s	% of flow	l/s	% of flow	l/s	% of flow	l/s	% of flow	l/s	% of flow
Barkers Creek at McKeown Road	69686 (BC1)	-	-	-	-	-	-	-	-	-	-	-	-
Barkers Creek at Saywell Ford	1696345 (BC3)	4	10%	8	13%	-1	-5%	5	17%	0	0%	26	10%
Barkers Creek at upstream Rokonui confluence	1696346 (BC5)	-2	-5%	-4	-7%	-2	-11%	-4	-16%	-3	-7%	-37	-17%
Barkers Creek at Middlemiss Road Bridge	1696347 (BC7)	5	12%	2	3%	2	10%	10	29%	4	9%	72.5	25%
Barkers Creek at upstream Water Race	1696348 (BC9)	-8	-23%	-9	-17%	-8	-67%	-5	-17%	-3	-7%	1	<1%
Barkers Creek at Sercombe Road	69685 (BC13)	24	41%	17	25%	20	63%	8	21%	49	53%	35	11%
Barkers Creek at upstream Waihi River	1696327 (BC17)	5	8%	2	3%	9	22%	11	22%	12	12%	42	11%

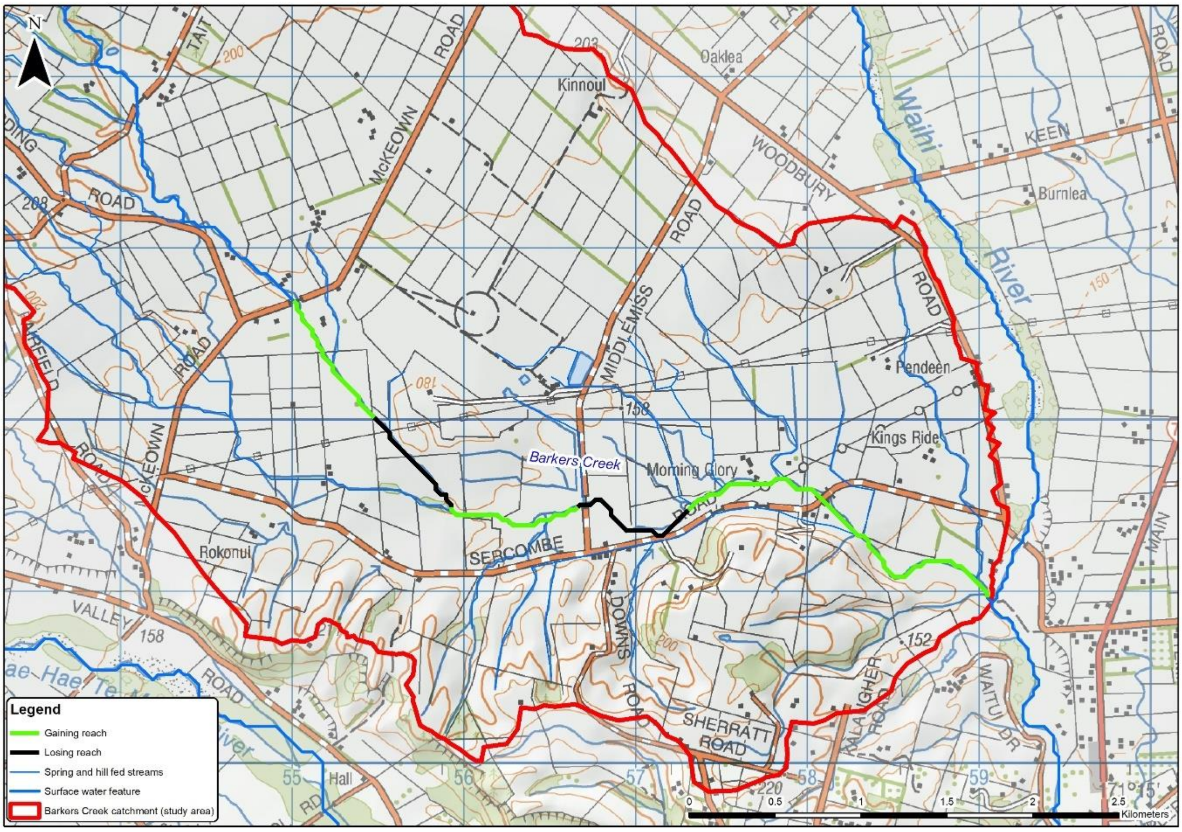

Figure 5-8: Gaining and losing reaches down Barkers Creek based on average gains/losses

5.2 Hydrochemistry

One round of broadscale sampling was undertaken in late August 2017. The raw analytical results from this sampling are presented in Appendix G.

5.2.1 Major ion chemistry

Major ions

Groundwater and surface water samples collected in the Barkers Creek catchment overall have low dissolved ion concentrations, although they are higher than samples collected in the Waihi River catchment.

The dominant water type in the Barkers Creek catchment is Ca-HCO_3 water (Figure 5-9). The Ca-HCO_3 signature reflects rainfall and surface water that has interacted with local geology caused by calcite dissolution and CO_2 in rain.

Four of the 40 water quality samples (two groundwater and two surface water) within the Barkers Creek catchment expressed a Na-HCO_3 water type signature. The two groundwater samples (BY19/0013 and J37/0202) are both deeper bores[11]. The Na-HCO_3 signature in these bores is likely a result of groundwater interaction with cover formation sediments (described in Section 3.4.2). SQ36223 (a drain on the south side of Barkers Creek) is fed by a number of springs and drains emanating within that basalt outcrops to the south of Barkers Creek. The Na-HCO_3 signature in SQ36223 is likely a combination of runoff and/or less chance of carbonate dissolution due to the basalt geology with the sodium signature source from rainfall (NaCl). The final site with a Na-HCO_3 is a drain nearest to the Barkers Creek/Waihi River confluence (SQ36224). This drain has a large catchment area at the bottom of the catchment and where groundwater is upwelling and discharging to surface water. The Na-HCO_3 signature in SQ36224 is therefore likely a reflection of LSR[12] effects.

[11] BY19/0013 is screened from 37-52 m and J37/0202 is screened from 58.66-62.66 m.

[12] Soil drainage from rain and irrigation water falling on land, forming a component of recharge to a groundwater system

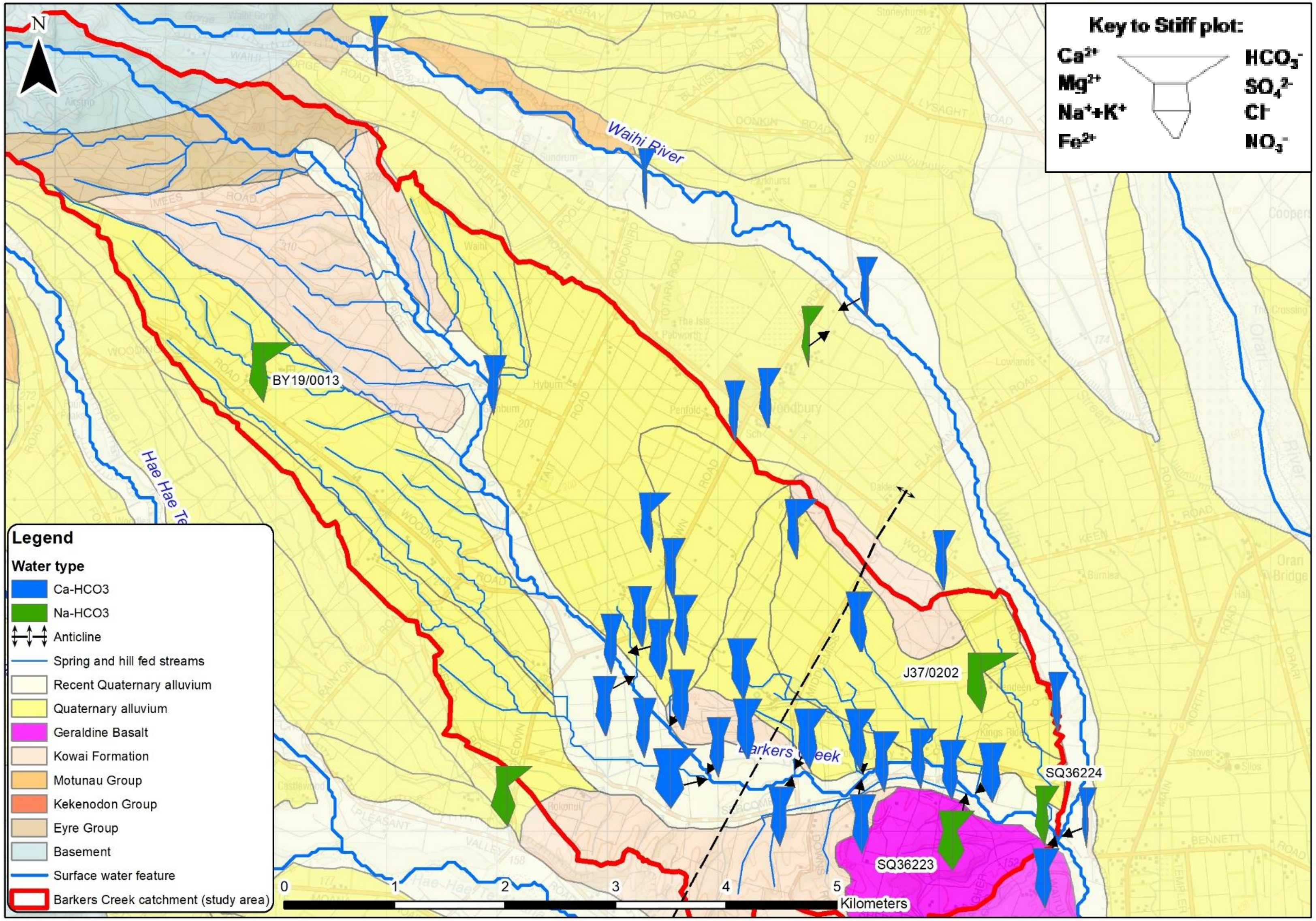

Figure 5-9: Stiff diagrams showing the composition of surface water and groundwater in the Barkers Creek catchment

Figure 5-10 shows a Piper diagram for surface water and groundwater sampled for this study. All samples cluster in the class of temporary hardness. This means the majority of samples collected have a similar signature (as indicated by the Stiff plots). There are six groundwater samples that plot verging towards alkali carbonate class on the Piper plot. Four of these are groundwater samples taken from greater than 30 m deep and two are shallower (10 m and 18 m deep). These samples are likely reflecting some evolution (ion exchange). The dominant cations range from calcium to sodium and the dominant anion is bicarbonate.

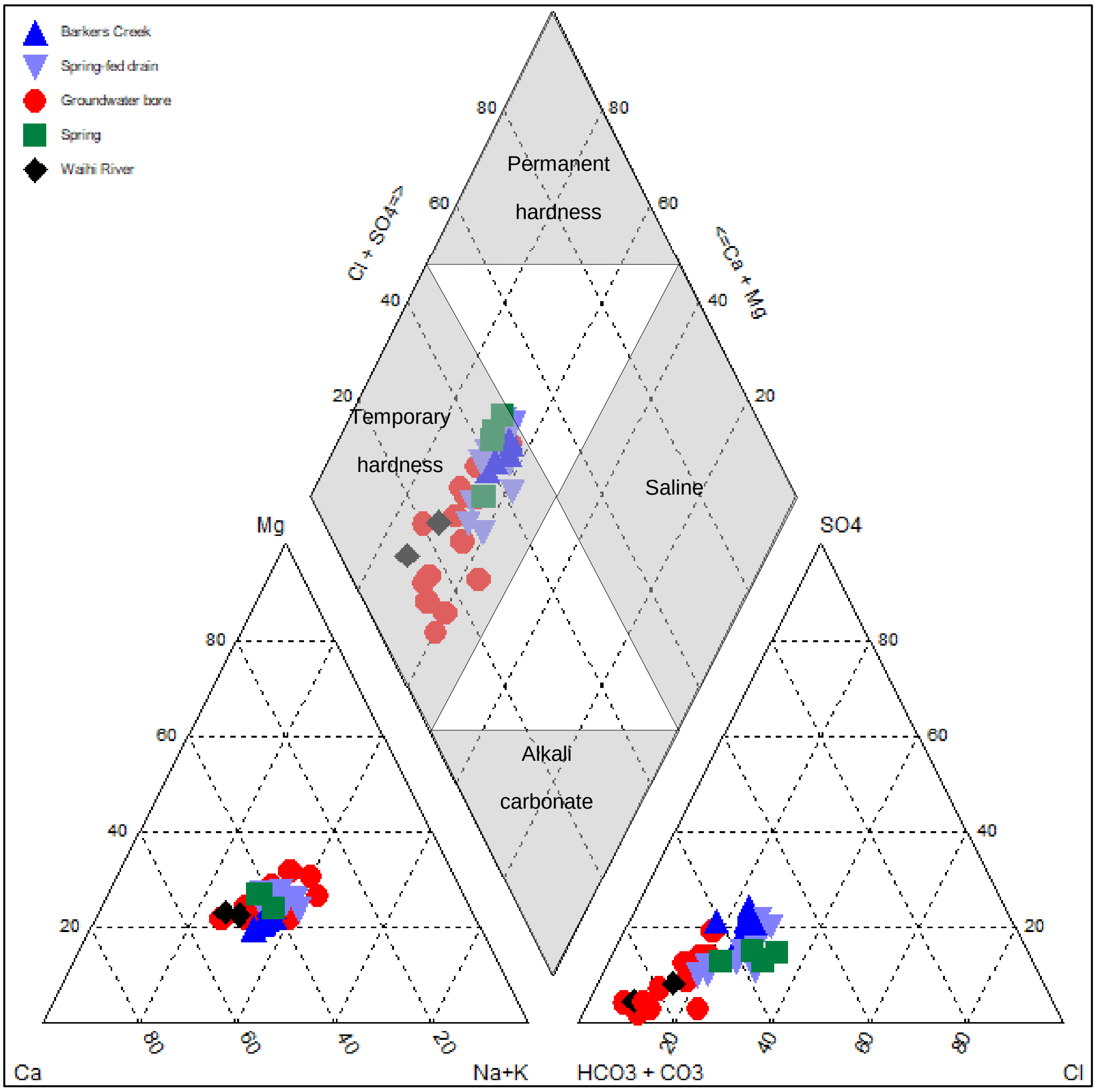

Figure 5-10: Piper plot showing the composition of groundwater and surface water in the Barkers Creek catchment

Electrical conductivity

Electrical conductivity is related to dissolved salts. More ions means water conducts electricity better. Ion sources include anthropogenic (e.g. fertiliser) and natural (e.g. interaction with aquifer material).

Throughout the Barkers Creek catchment, electrical conductivity is low (less than 20 mS/m; Figure 5-11). This reflects short flow paths/residence time between the recharge and discharge zones for groundwater. Electrical conductivity further suggest there are only minor anthropogenic contaminant sources and/or a low degree of water-rock chemical interaction, which for uniform geology might assume as a proxy for groundwater age. There is however an increase in conductivity between the top and bottom of the catchment. Electrical conductivity is higher than that is observed in the Waihi River catchment to the north.

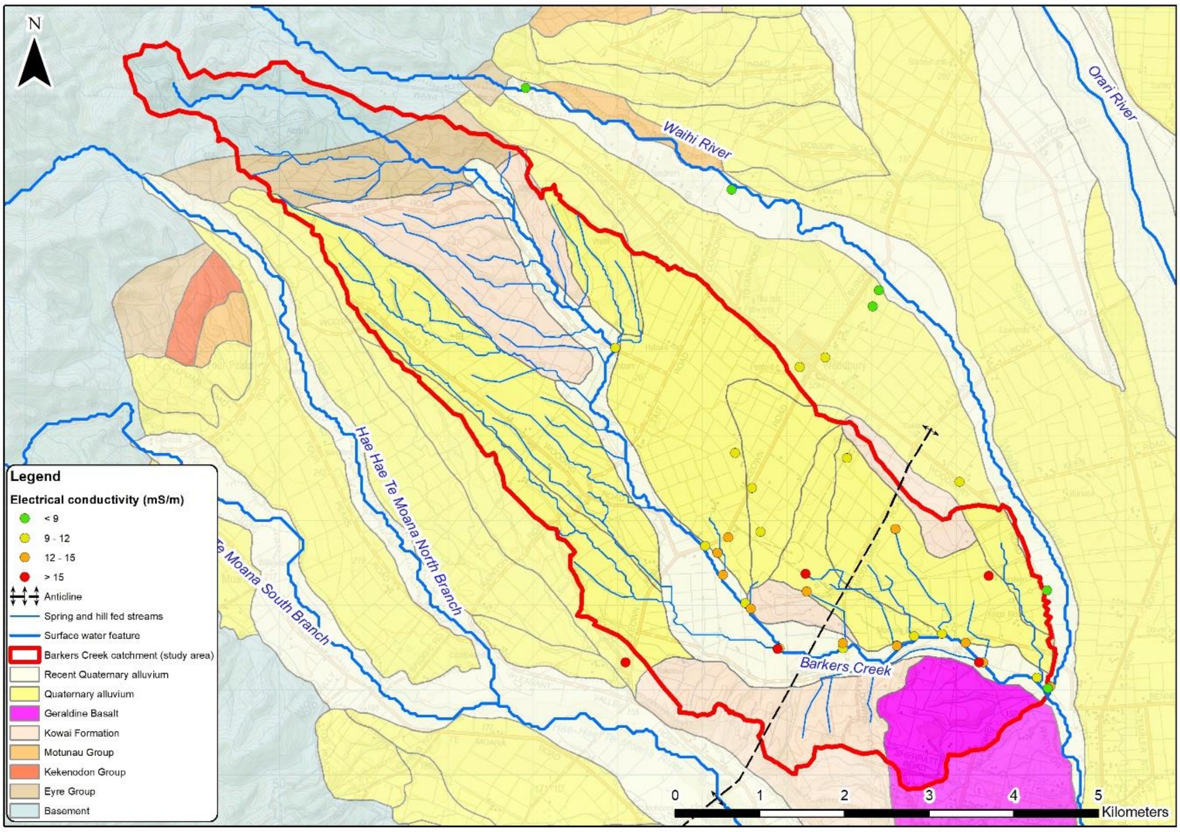

Figure 5-11: Electrical conductivity in the Barkers Creek catchment

5.2.2 Hierarchical cluster analysis

HCA resulted in the separation of two clusters and four sub-clusters. The results of the HCA are presented in Figure 5-12 as a dendrogram and spatially in Figure 5-13. Two clusters form at A and B with a separation threshold of 200, and four sub-clusters form at A1, B1, B2 and B3 at a separation threshold of 90.

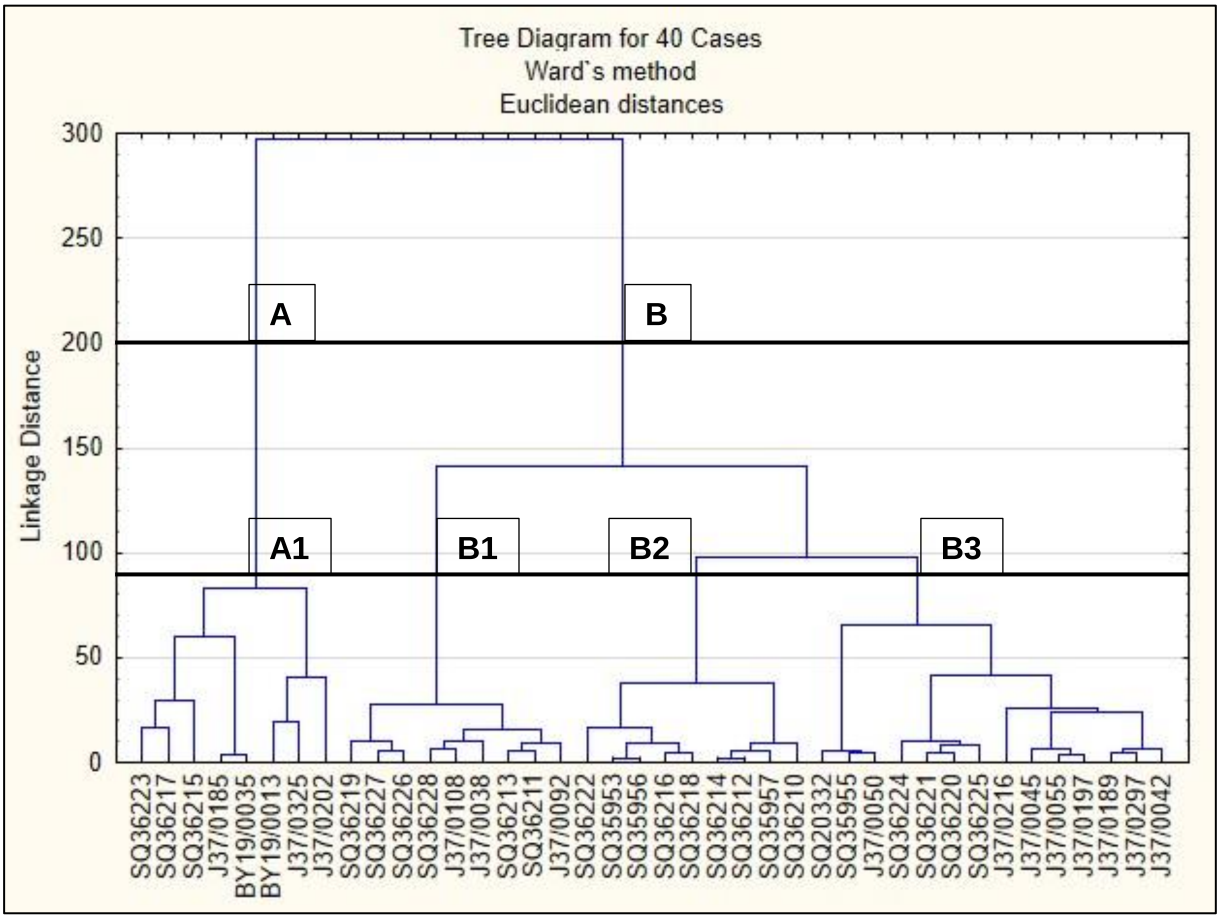

Figure 5-12: Dendrogram resulting from HCA showing the first cluster formation A, B at threshold 200 and four sub cluster A1, B1, B2 and B3 at threshold 90

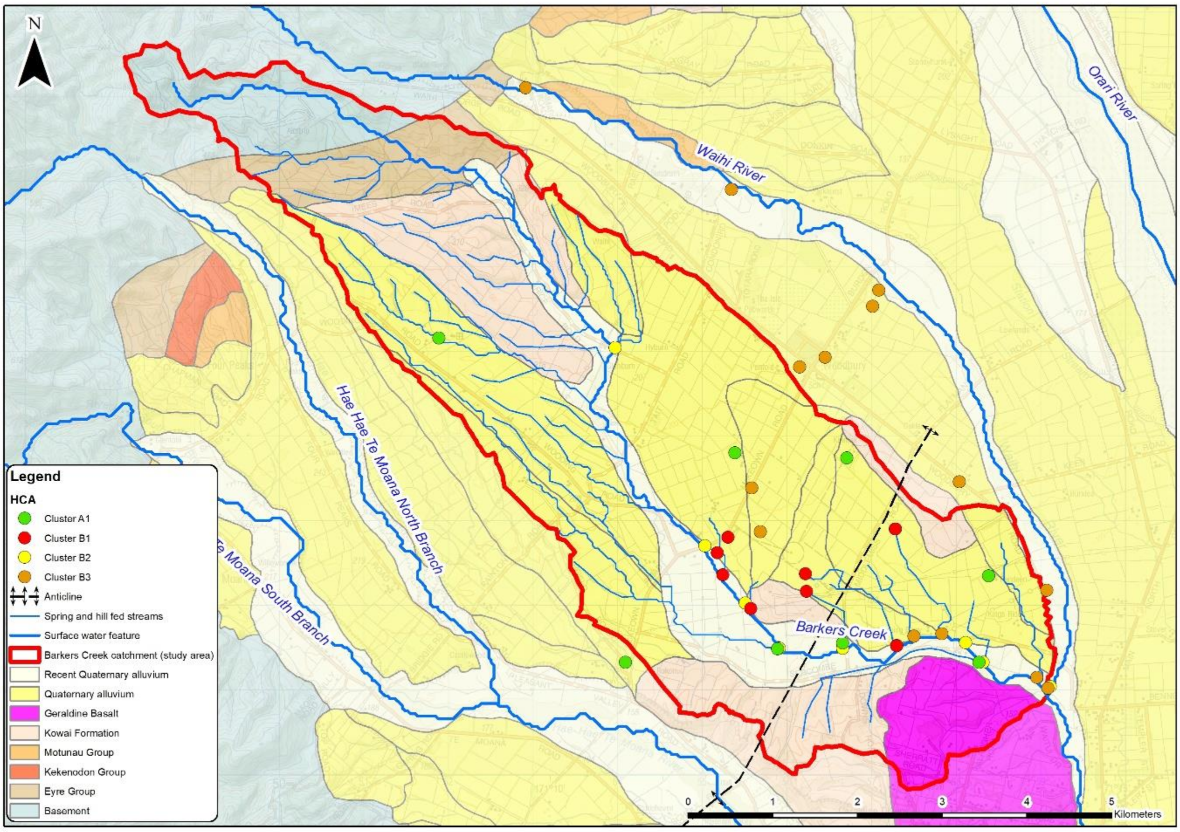

Figure 5-13: Spatial distribution of clusters resulting from HCA

The members of the four sub cluster groups formed by Wards method of the HCA and their member composition of surface water and groundwater sites are listed in Table 5-6. Cluster B3 has the highest cluster membership at 14 sites and includes all sites that fall in the Waihi River catchment that were sampled for this study. Without these sites outside the Barkers Creek catchment, cluster B3 would have 5 members.

Table 5-6: HCA cluster groups

Cluster	Cluster members	Groundwater site	Surface water site	Total sites
A1	BY19/0035, BY19/0035, J37/0185, J37/0202, J37/0325 SQ36215, SQ36217, SQ36223	5	3	8
B1	J37/0038, J37/0092, J37/0108, SQ36226, SQ36227, SQ36228, SQ36211, SQ36213, SQ36211	6	3	9
B2	SQ36222, SQ36210, SQ35957, SQ36218, SQ36212, SQ36214, SQ36216, SQ35956, SQ35953	0	9	9
B3	J37/0042, J37/0045, J37/0050, J37/0055, J37/0189, J37/0197, J37/0216, J37/0297, SQ36225, SQ20332, SQ36220, SQ36221, SQ36224, SQ35955	9	5	14

To identify and assess the specific differences between each of the four clusters formed using HCA, box-plots were used (Appendix H). The characteristics of each cluster are described below.

Cluster A1 (5 groundwater, 3 surface water sites) includes all sampled bores within the Barkers Creek catchment deeper than 30 m (3 bores) one shallower bore (18 m deep) on the northern boundary of the catchment, and one 10 m bore located outside the southern boundary of the catchment. A1 also includes three spring-fed drains that feed Barkers Creek. Cluster A1 has characteristically higher alkalinity, iron, magnesium, manganese, and silica, and while there are large ranges in dissolved oxygen and sulphate, the concentrations are lower than what is observed in the other three clusters. This cluster likely represents older (more evolved) groundwater that has interacted with the older Quaternary alluvium and cover formation geology.

Cluster B1 (6 groundwater and 3 surface water sites) includes all bores less than 10 m deep sampled within the Barkers Creek catchment, and 3 spring-fed drains. The defining characteristic of this cluster is the higher nitrate-nitrogen concentrations. This cluster could be reflecting the effects of land use practices.

Cluster B2 (9 surface water sites) includes all 8 sites along Barkers Creek and 1 spring-fed drain. This cluster is characterised by higher pH, dissolved oxygen and sulphate concentrations, combined with lower magnesium, silica and sodium concentrations.

Cluster B3 (9 groundwater and 5 surface water sites) include all sites outside the northern boundary of the Barkers Creek catchment along with 2 groundwater and 3 spring-fed drains within the Barkers Creek catchment. This cluster has lower chloride, conductivity, calcium, total hardness, pH and sulphate relative to the other three clusters. This cluster likely reflects Waihi River recharge.

5.2.3 Redox

Figure 5-14 shows the redox state for groundwater sampled during this study. In general, groundwater in the catchment is oxic. Consequently, there is little potential for denitrification to occur. There are three bores with a ‘mixed’ redox state, as results can be attributed to both oxic and anoxic redox states. J37/0202 (63 m deep) and BY19/0013 (52 m deep) and BY19/0035 (18 m deep) contained anomalous (with respect to other samples collected for this study) iron (0.27 mg/L and 2.1 mg/L) and manganese (0.101 mg/L and 0.033 mg/L) and low nitrate-nitrogen concentrations (0.004 mg/L and 0.008 mg/L respectively). Like these bores, BY19/0035 had anomalous iron (0.18 mg/L) and manganese (0.048 mg/L) but a nitrate-nitrogen concentration (2.6 mg/L) that is comparable to other groundwater samples collected nearby (see Section 5.3).

With the exception of the two spring-fed drains (SQ36215 and SQ36223) entering Barkers Creek on its southern side, all surface water sites have an oxic redox state. D6 and D15 are both characterised by high iron concentrations (0.62 mg/L and 0.12 mg/L respectively) and low nitrate-nitrogen concentrations (0.72 mg/L and 0.051 mg/L respectively).

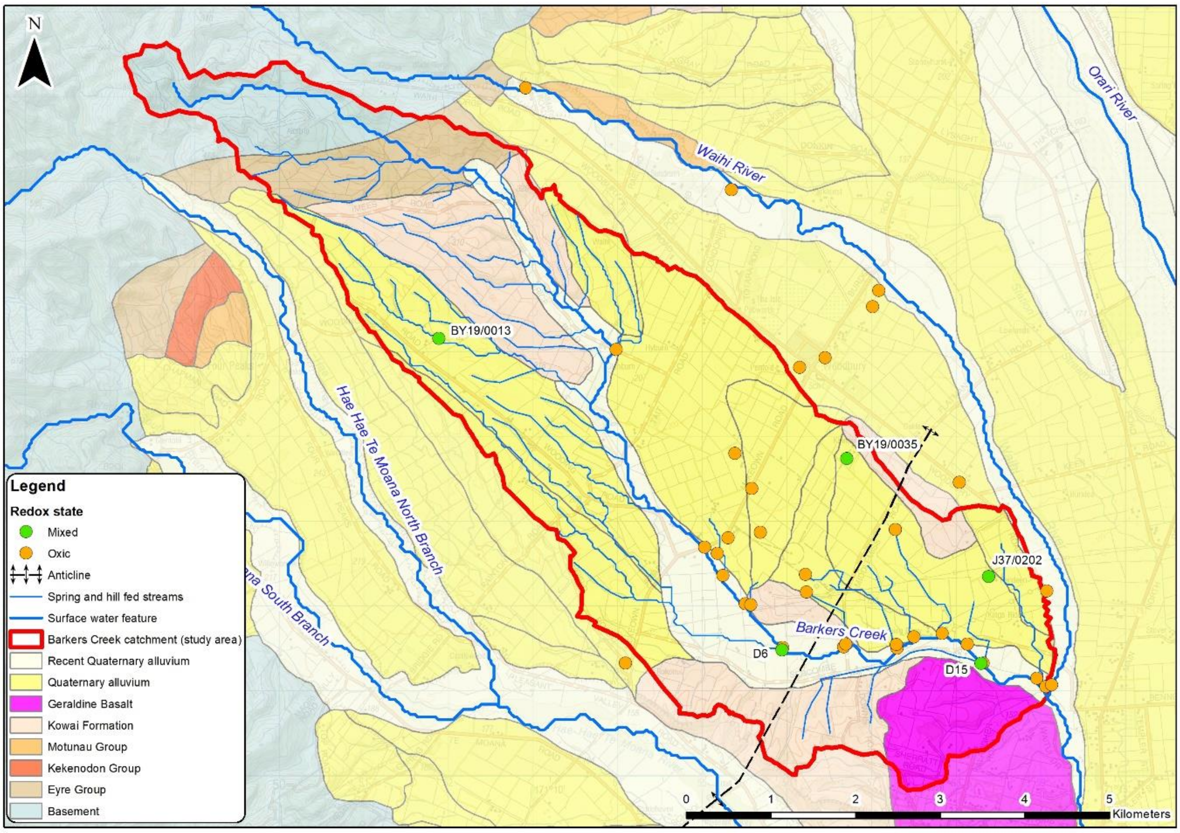

Figure 5-14: Redox state of groundwater and surface water in the Barkers Creek catchment

5.3 Nutrients

Groundwater and surface water sampling of nutrients was undertaken fortnightly at 5 surface water sites and bimonthly at 19 surface water and 5 groundwater sites. Nitrate-nitrogen and dissolved reactive phosphorus (DRP) are the most relevant to this study. The raw analytical results from this sampling are presented in Appendix I.

5.3.1 Nitrate-nitrogen concentrations

Across the lower Barkers Creek catchment nitrate-nitrogen concentrations in groundwater are above background levels (i.e. greater than 2.5 mg/L; Figure 5-15). Compared to bores sampled in the Waihi River catchment during this study, nitrate-nitrogen concentrations are higher. Figure 5-16 shows that nitrate-nitrogen concentrations are higher in shallower bores and generally decrease with depth. During the broadscale water quality survey, the maximum nitrate-nitrogen concentration measured was 8.5 mg/L.

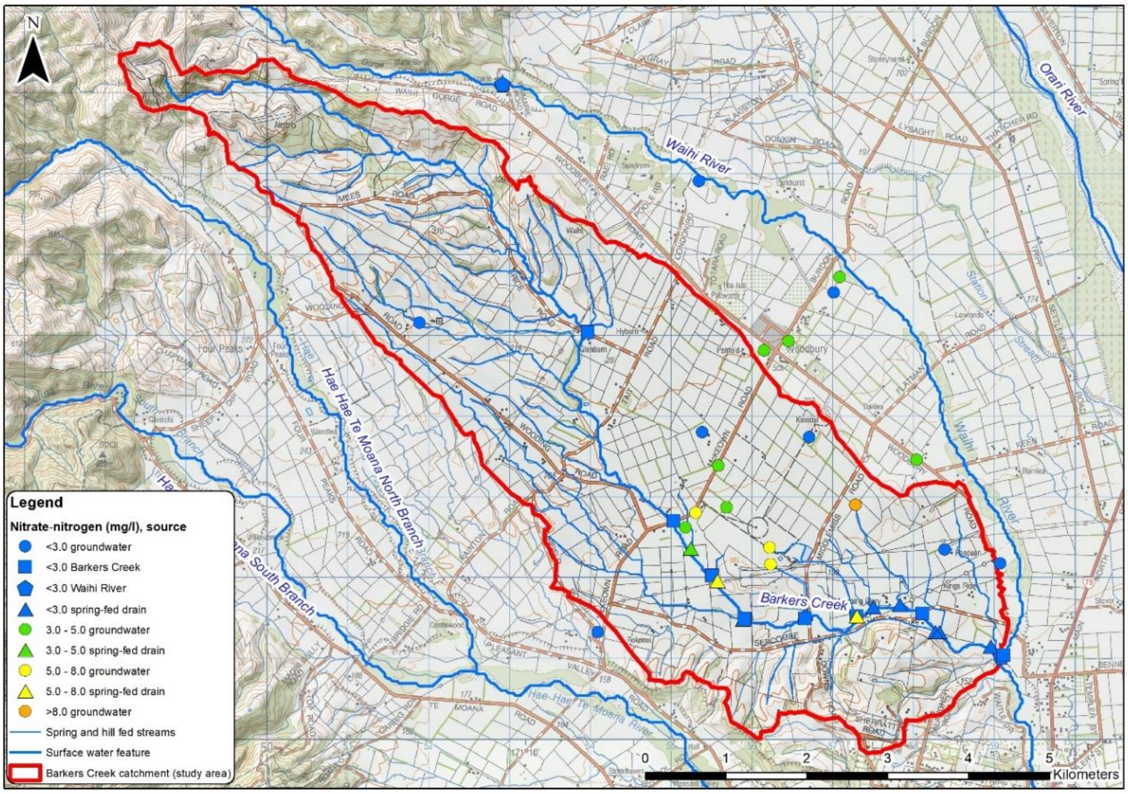

Figure 5-15: Nitrate-nitrogen concentration distribution, as determined from broadscale sampling in August - September 2016

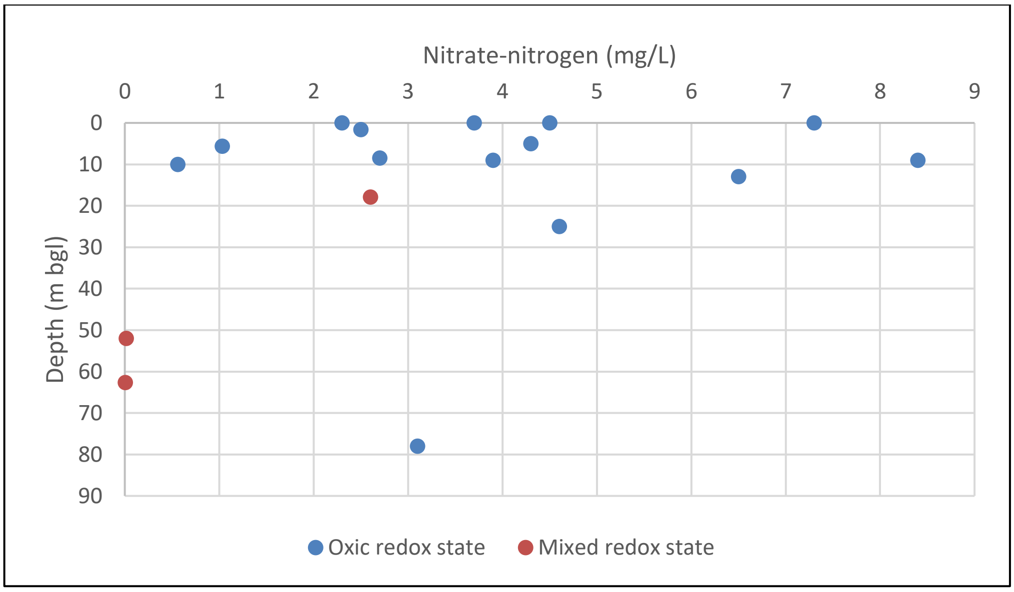

Figure 5-16: Nitrate-nitrogen concentration vs depth of bores sampled during August 2016 for this study

The five groundwater sites included in the bimonthly sampling programme had variable nitrate-nitrogen concentrations over the study period (Figure 5-17). The deeper bores

(J37/0202[13] and J37/0185) were stable throughout the monitoring period, with little variation in measured concentrations. The 3 shallow bores had variable concentrations across the monitoring period, reaching a maximum of 10.9 mg/L nitrate-nitrogen. As Figure 5-17 shows, nitrate-nitrogen concentrations typically increased following periods of increased rainfall and decreased following drier periods.

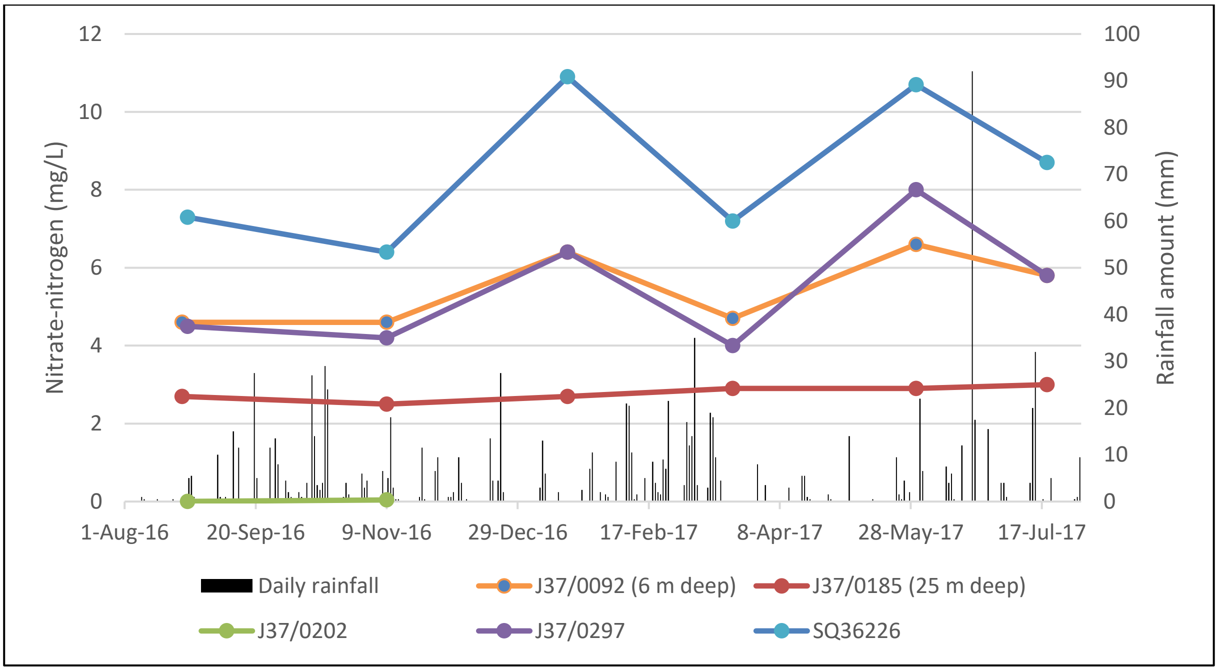

Figure 5-17: Bimonthly nitrate-nitrogen concentrations in groundwater

In surface water, there is an overall increasing pattern in nitrate-nitrogen concentrations along the length monitored (i.e. between Rice Road, BC0 and Barkers Creek confluence with the Waihi River, BC17) as shown in Figure 5-18. Between the upstream Rokonui monitoring site and Middlemiss Road there is a consistent decrease in nitrate-nitrogen concentrations. As there are no drain inputs between these two sites, this is presumably attributed to baseflow inputs from groundwater seeping with less nitrate-nitrogen. This is consistent with the gains and losses identified in Section 5.1.4.

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[13] Only two samples were collected from J37/0202 due to onsite pump failure.

Most of the spring-fed drains exhibited variable nitrate-nitrogen concentrations over the monitoring period. The maximum nitrate-nitrogen measured in any of the spring-fed drains was 9.2 mg/L (as shown in Figure 5-19). As the data in Figure 5-18 show, concentrations in the spring-fed drains generally mimic the temporal patterns observed in groundwater (Figure 5-17), reflecting their groundwater fed nature.

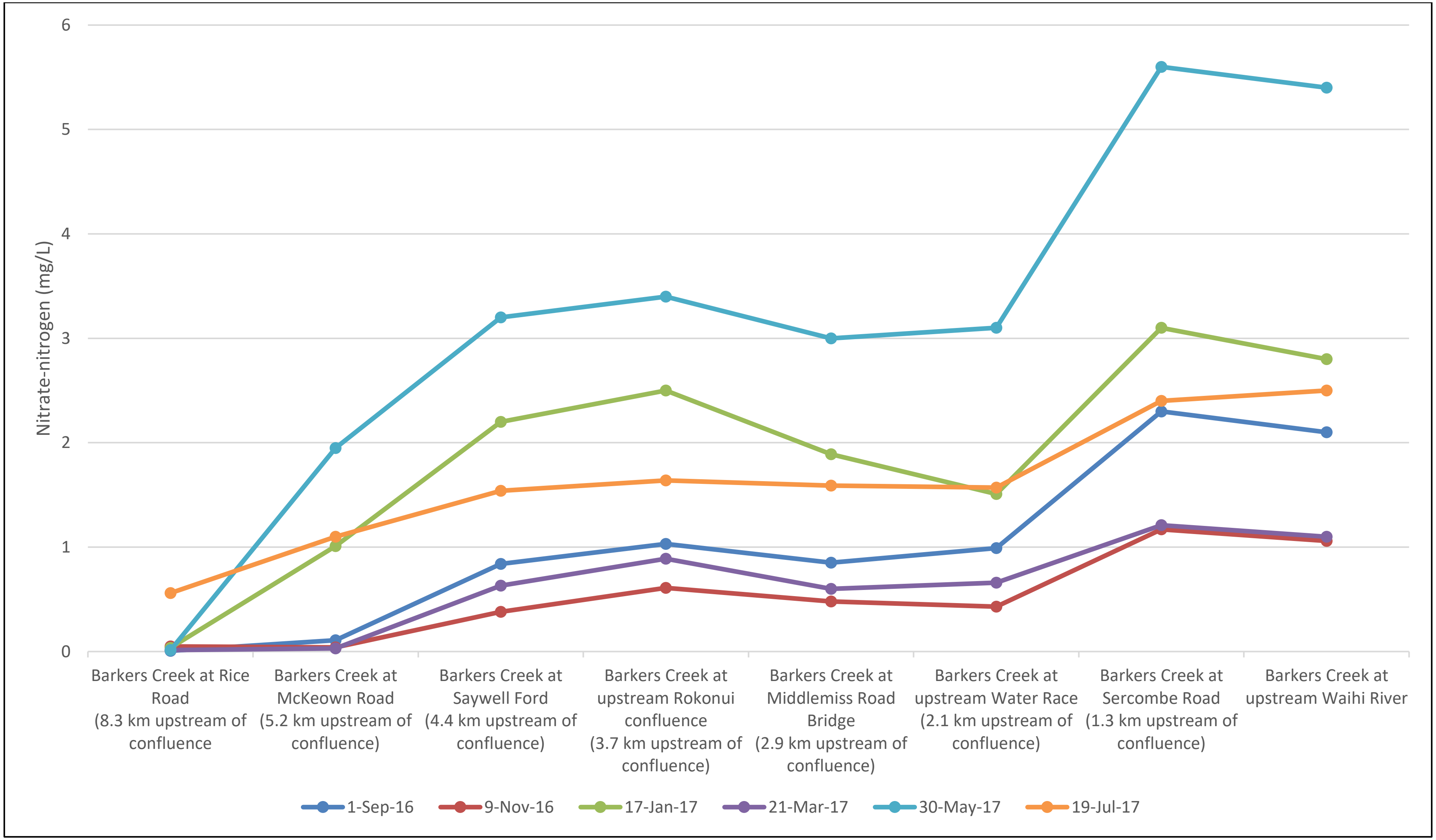

Figure 5-18: Changes in nitrate-nitrogen concentrations along Barkers Creek

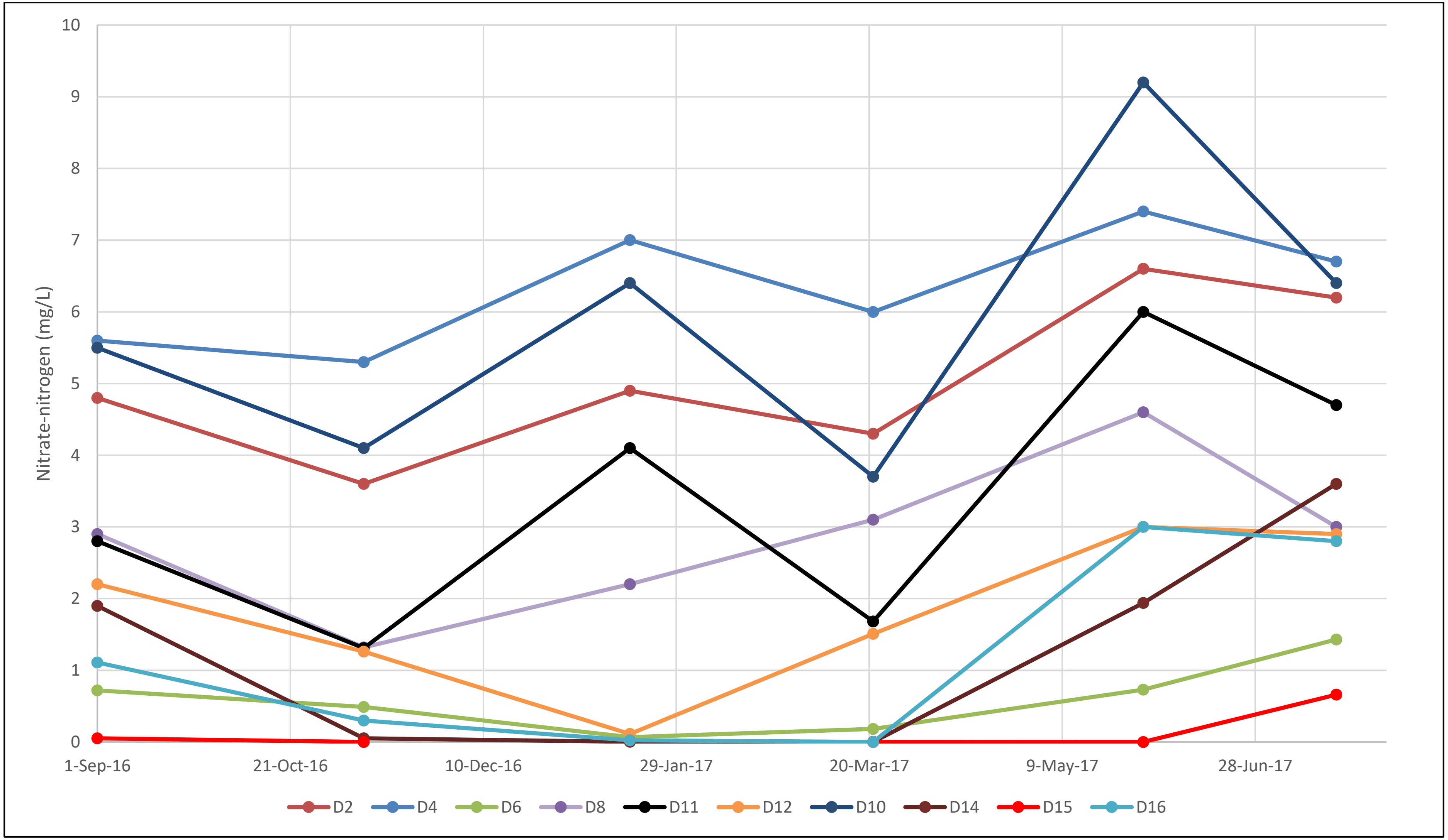

Figure 5-19: Bimonthly nitrate-nitrogen concentrations in the spring-fed drains

5.3.2 Dissolved reactive phosphorus

As shown in Figure 5-20, across the Barkers Creek catchment DRP concentrations in groundwater are enriched (0.009-0.03 mg/L; based on The New Zealand Periphyton Guideline (2000) thresholds). Compared to bores sampled in the Waihi River catchment for this study, DRP concentrations in the Barkers Creek catchment are higher. Figure 5-21 shows that there is little correlation between DRP concentration and depth, suggesting concentrations are naturally driven (i.e. sourced from sediment). The maximum DRP measured during the broadscale water quality survey was 0.079 mg/L, which falls in the excessive concentration threshold

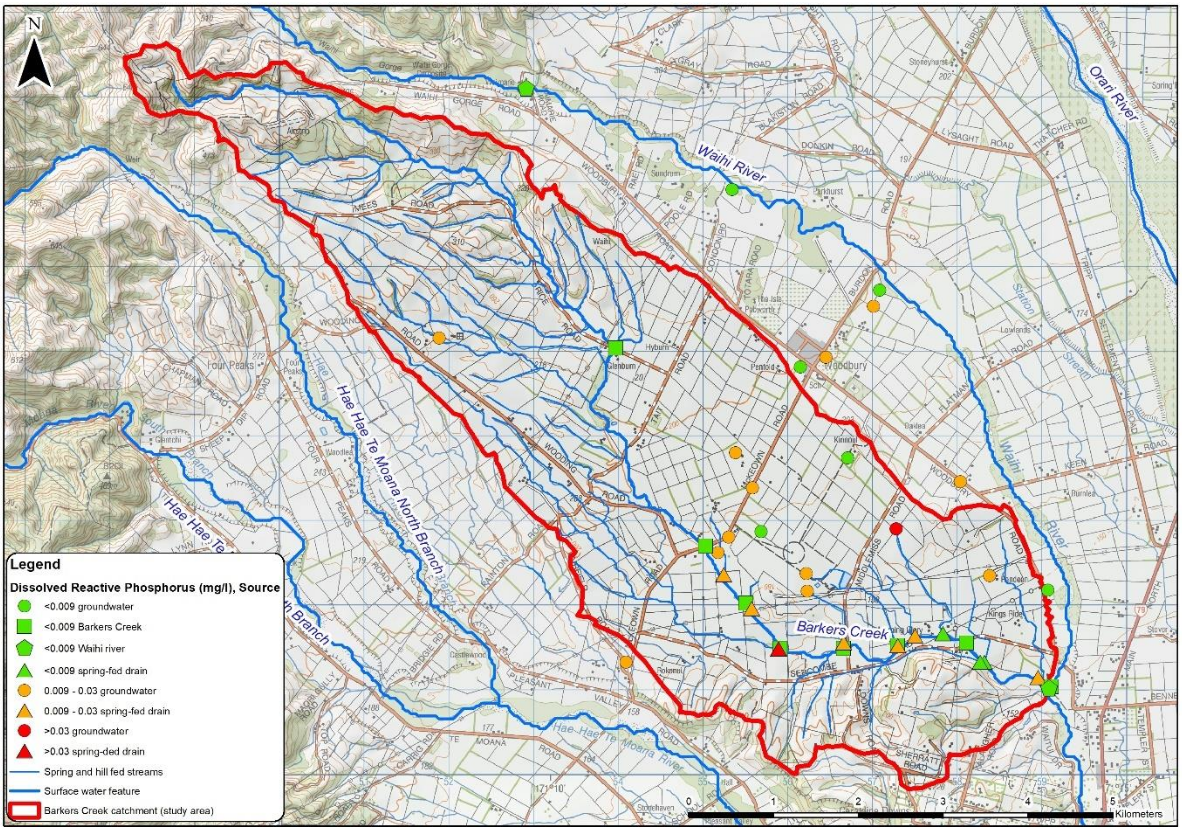

Figure 5-20: DRP concentration distribution, as determined from broadscale sampling in August - September 2016

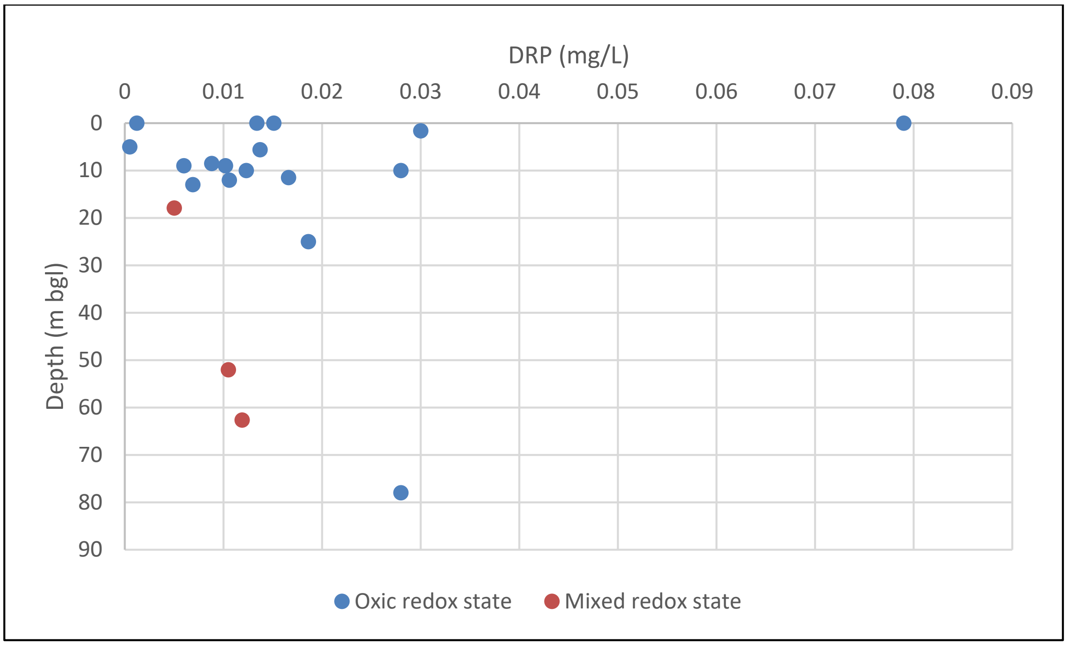

Figure 5-21: Dissolved reactive phosphorus concentration vs depth of bores sampled during August 2016 for this study

The five groundwater sites included in the bimonthly sampling programme had variable DRP concentrations over the study period (Figure 5-22). The deeper bores (J37/0202[13] and J37/0185) generally had higher DRP concentrations compared to the shallower bores. This suggests a natural source of phosphorus is present at depth. The 3 shallow bores had little variation in DRP concentrations across the monitoring period, reflecting that land use is not likely having a significant impact on DRP concentrations within the catchment.

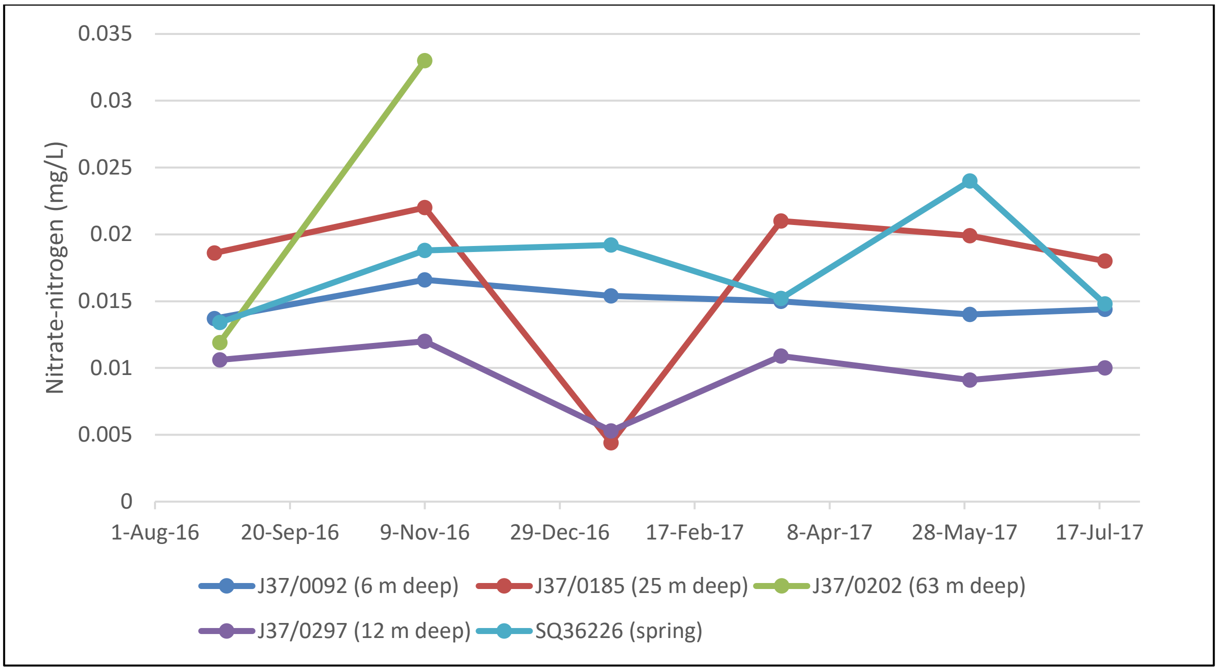

Figure 5-22: Bimonthly DRP concentrations in groundwater

In Barkers Creek DRP concentrations increase and decrease between Rice Road and the confluence with the Waihi River, with an overall increase between the most upstream and most downstream sites (as shown in Figure 5-23). From the upstream Rokonui monitoring site there is generally an increase in DRP concentrations through to the confluence with the Waihi River. This is likely reflecting the groundwater seepage occurring along the majority of this reach and is consistent with the gains and losses identified in Section 5.1.4. There was an anomalous DRP concentration measured in J37/0185 during the 17 January 2017 sampling run.

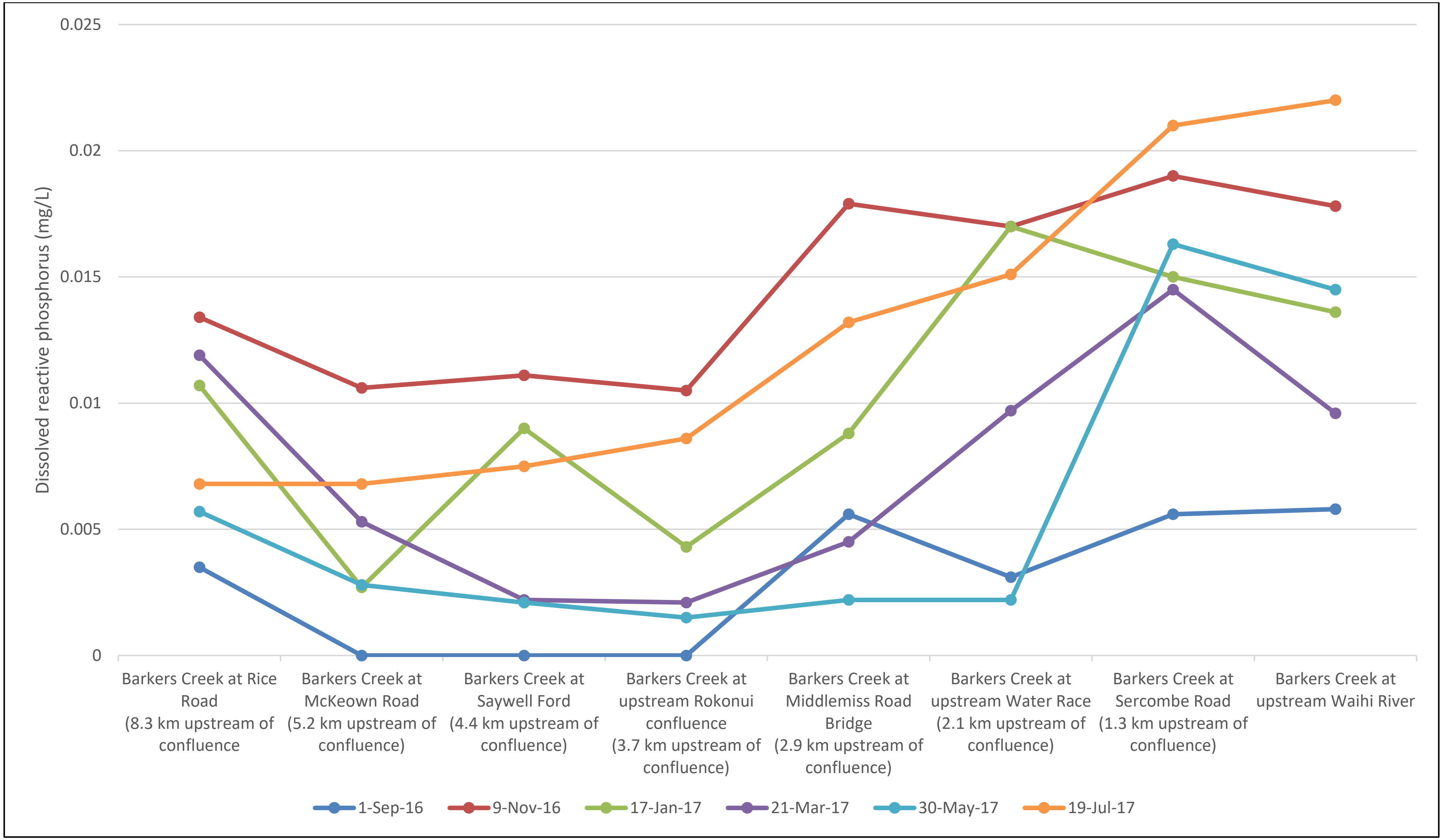

Figure 5-23: Changes in DRP concentrations along Barkers Creek

Most of the spring-fed drains have similar DRP trends and concentrations (Figure 5-19). This suggests that climate has little influence on DRP concentrations. The exception to this is the DRP concentrations measured in Rokonui Drain (D6). Through the bulk of the monitoring period this drain had a significantly higher DRP concentration compared to the other drains. During sampling, the water in the drain was typically turbid, and the higher DRP concentrations could be reflecting land use within the drains catchment and increased stock access as much of the drain is unfenced.

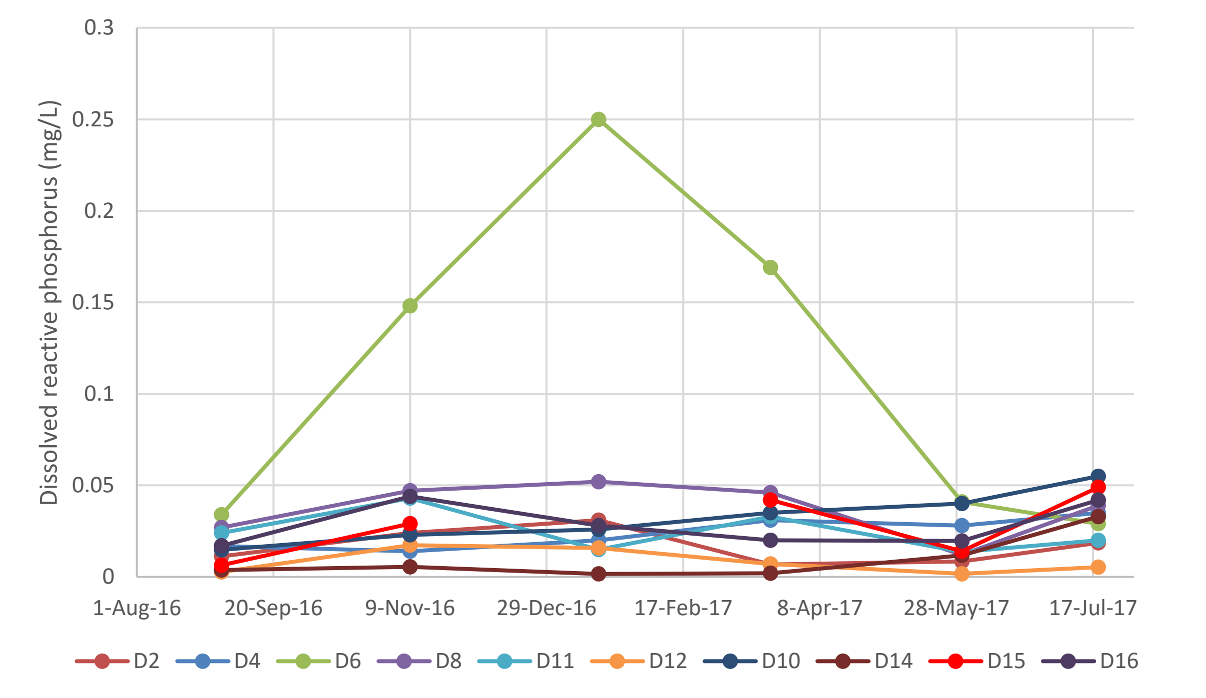

Figure 5-24: Changes in DRP concentrations along the spring-fed drains feeding Barkers Creek

5.3.3 Nitrogen and phosphorus loads

To assess the annual load being exported from the Barkers Creek catchment, a synthetic flow record was created for BC17 (Barkers Creek at upstream Waihi River) to provide the best estimate. This is however expected to be a small underestimate as the calculations were undertaken using the 26 fortnightly samples taken at or near baseflow. As outlined in Section 5.4, for short periods of time under storm flow events, nitrate-nitrogen load can exceed the loads under baseflow conditions. The synthetic flow record was created by correlating the concurrent spot gaugings (6 gauging runs) with the BC13 (Barkers Creek at Sercombe Road) surface water flow recorder site. The resultant relationship could then be used to calculate flows at BC17 across the 12 month monitoring period. Results from this correlation are presented in Appendix J. To best gauge the significance of the load exported from the Barkers Creek catchment a comparison was made to the Waihi River. A synthetic flow record was also created for the Waihi River monitoring site, upstream of the confluence with Barkers Creek (W18). The results of the relationship between W18 Waihi River at upstream Barkers and an Environment Canterbury recorder site on the Waihi River at Waimarie are also presented in Appendix J. Using this flow relationship, a synthetic flow record for W18 could be created.

Using the synthetic flow records, a daily load could be created for each site using the sampling results from the 26 rounds of sampling undertaken at each site (Appendix K). From the fortnightly sampling dataset, the average daily nitrate-nitrogen load exiting via Barkers Creek is ranged between 6 kg (mean daily flow of 55 l/s) and 244 kg (mean daily flow of 565 l/s). Assuming that the measured biweekly concentrations held constant between measurements, the annual export of nitrate-nitrogen from Barkers Creek to the Waihi River equated to 54 tonnes. The Waihi River (W18) had a narrower range in measured nitrate-nitrogen loads compared to Barkers Creek (BC17). Measured daily loads were between 18 kg (mean daily flow of 544 l/s) and 100 kg (447 l/s) for a total annual load of 30 tonnes. This equates to a 180% nitrate-nitrogen load increase in the Waihi River downstream of the confluence with Barkers Creek

Like nitrate-nitrogen loads, daily DRP loads from the fortnightly measurements were higher in Barkers Creek (BC17) compared to the Waihi River (W18). Barkers Creek had a daily load range of between 0.6 kg an 11 kg and the Waihi River between 0.1 kg and 1 kg (Appendix K). The annual average DRP load is also higher in Barker Creek compared with the Waihi River. Using the same approach as with nitrate-nitrogen, annual average load under baseflow concentrations in Barkers creek (BC17) is 0.4 tonnes compared 0.08 tonnes in the Waihi River (W18). This equates to a 500% increase in DRP load in the Waihi River downstream of the confluence with Barkers Creek.

While useful in assessing an annual load estimate, the synthetic flow records are less useful in assessing the relative load contributions from the various sources (i.e. spring-fed drains, groundwater and Barkers Creek above McKeown Road). To assess the relative load contributions from Barkers Creek, spring-fed drains and groundwater, a mass balance (same as the approach for gaining/losing reaches) was undertaken using the bimonthly data. The six concurrent gauging (for flow on the main stem and spring-fed tributaries) runs coupled with nitrate-nitrogen and DRP concentrations were used to undertake the mass balance (results are presented in Table 5-7 and Figure 5-25 for nitrate-nitrogen and Table 5-8 and Figure 5-26 for DRP). The results of this mass balance can then be used to further understand the relationship between groundwater and surface water, particularly nutrient transfer pathways, in the lower Barkers Creek catchment.

Table 5-7: Naturalised nitrate-nitrogen load mass balance for Barkers Creek

Site name	Site number	Date					
		1/9/2016	9/11/2016	17/1/2017	21/3/2017	30/5/2017	19/7/2017
		kg/day	kg/day	kg/day	kg/day	kg/day	kg/day
Barkers Creek at McKeown Road	69686 (BC1)	0.3	0.2	1.8	0.1	7.6	21.5
Barkers Creek at Saywell Ford	1696345 (BC3)	0.9	0.4	1.5	1.0	7.7	27.9
Barkers Creek at upstream Rokonui confluence	1696346 (BC5)	0.2	0.7	0.3	-0.4	6.2	21.5
Barkers Creek at Middlemiss Road Bridge	1696347 (BC7)	-0.1	0.1	-0.6	-0.6	6.4	30.5
Barkers Creek at upstream Water Race	1696348 (BC9)	-1.5	-1.3	-3.3	-1.7	5.2	28.1
Barkers Creek at Sercombe Road	69685 (BC13)	4.1	0.04	0.4	-1.9	29.6	38.5
Barkers Creek at upstream Waihi River	1696327 (BC17)	3.4	-0.5	0.9	-1.2	33.0	51.3

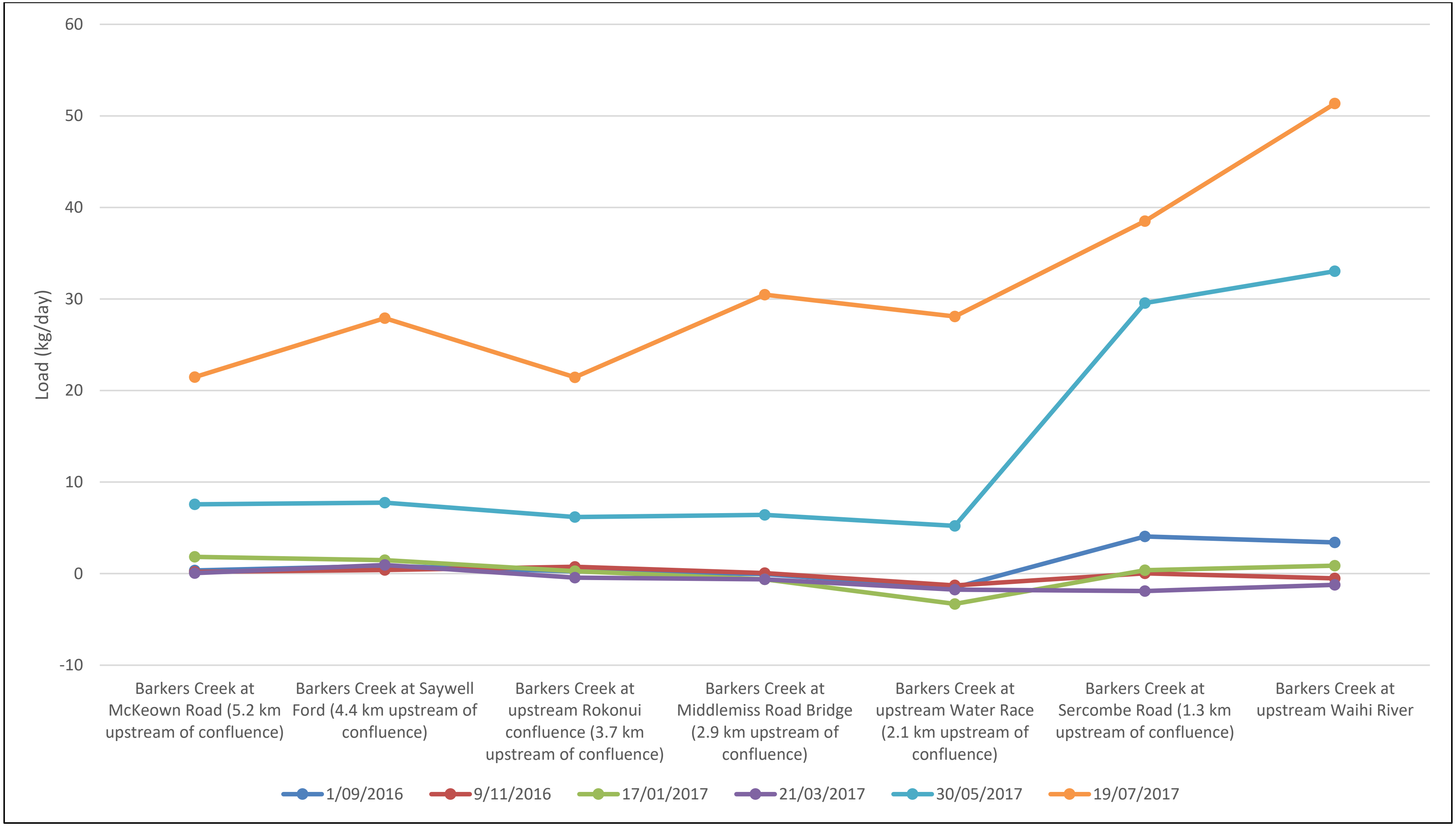

Figure 5-25: Naturalised nitrate-nitrogen load mass balance

Table 5-8: Naturalised DRP load mass balance for Barkers Creek

Site name	Site number	Date					
		1/9/2016	9/11/2016	17/1/2017	21/3/2017	30/5/2017	19/7/2017
		kg/day	kg/day	kg/day	kg/day	kg/day	kg/day
Barkers Creek at McKeown Road	69686 (BC1)	0.002	0.050	0.005	0.011	0.011	0.133
Barkers Creek at Saywell Ford	1696345 (BC3)	-0.004	0.054	-0.003	0.005	-0.001	0.150
Barkers Creek at upstream Rokonui confluence	1696346 (BC5)	-0.008	0.046	-0.022	-0.006	-0.016	0.129
Barkers Creek at Middlemiss Road Bridge	1696347 (BC7)	0.000	0.002	-0.070	-0.024	-0.034	0.299
Barkers Creek at upstream Water Race	1696348 (BC9)	-0.033	-0.041	-0.077	-0.025	-0.042	0.319
Barkers Creek at Sercombe Road	69685 (BC13)	-0.037	-0.021	-0.075	-0.028	0.025	0.415
Barkers Creek at upstream Waihi River	1696327 (BC17)	-0.034	-0.040	-0.075	-0.008	0.000	0.505

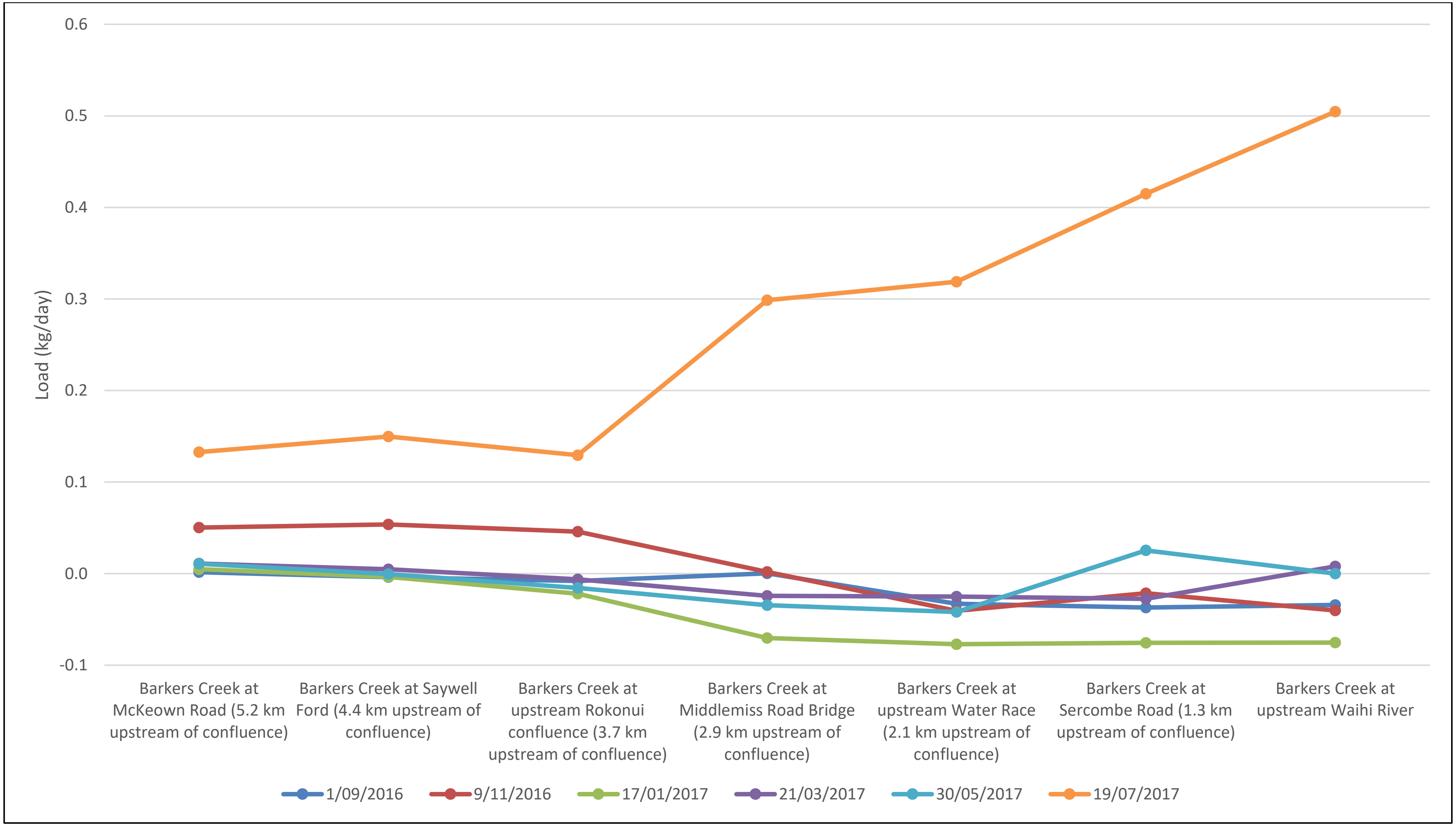

Figure 5-26: Naturalised DRP load mass balance

There is a gain in nitrate-nitrogen load in Barkers Creek between McKeown Road the Saywell Ford. Between the Saywell Ford and upstream of the Rokonui drain there is a loss in load. From here, downstream to Middlemiss Road there is a loss in load (4 of 6 sampling events). Downstream of Middlemiss Road to upstream of the Water Race drain there is a nutrient load loss. From this site there is a large gain in load through to Sercombe Road (4 of six sampling events). From Sercombe Road through to Barkers Creek confluence with the Waihi River there is a complex gain/loss DRP load relationship (3 sampling events showed a load loss, 2 showed a load gain and 1 had no load change).

There is a loss in DRP load in Barkers Creek between McKeown Road upstream of the Water Race. From this site there is a gain in load through to Barkers Creek confluence with the Waihi River.

Nitrate-nitrogen and DRP loads presented in Appendix L show the relative load contribution from Barkers Creek upstream of McKeown Road, all the spring-fed drains below McKeown Road and diffuse groundwater seepage. 69% of the load in Barkers Creek comes from the spring-fed drains. Of these drains, D4 carries 9.4%, D10 carries 35.5% and D11 carries 10.7% of the daily loads exported to Barkers Creek. 11% comes from the catchment upstream of McKeown Road. The balance is assumed to come diffuse groundwater seepage which accounts for the remaining 20%. Given all spring-fed drains below McKeown Road have been measured, this is a reasonable assumption. The majority of DRP load exported from Barkers Creek to the Waihi River originates from D6 (15.1%), D8 (10.2%), D10 (32.9%), and D11 (8.6%). A further 13% is from Barkers Creek upstream of McKeown Road. The remainder is assumed to be from the remaining spring-fed drains and the mass balance suggests there is little DRP load gained from diffuse groundwater seepage.

5.4 Storm flow event analysis

Storm event analysis occurred for three rainfall events across the study period. Initially, storm events were being sampled to understand seasonal changes in nutrient and sediment loads in Barkers Creek through storm events. Numerous equipment failures resulted in a change in the aim, to understanding how different magnitude and rainfall intensity storm events impacted export to Barkers Creek.

Two sites were sampled along Barkers Creek, one up-catchment at McKeown Road (BC1) and one down-catchment at Sercombe Road (BC13) using an autosampler. Over each event, 10 samples were collected from each autosampler for nutrient (nitrogen and phosphorus) and TSS load analysis at various points across the event hydrograph. The three storm/rainfall events targeted occurred on 11-13 March 2017, 12-13 April 2017 and 21-22 July 2017.

5.4.1 Event 1 – March 2017

Event analysis occurred over a three day period from 11-13 March 2017. The total rainfall recorded at Environment Canterbury's Woodbury rainfall site over this period was 52 mm. 41.5 mm was recorded over the 11th and 12th of March with a further 10.5 mm on the 13th March. Rainfall amounts were relatively consistent across the duration of the event and peaked in intensity at 2.5 mm per hour. As can be seen in Figure 5-27, flows in Barkers Creek responded with a relatively consistent high flow peak across the event, peaking at 0.411 m^3/sec at 3am on the 14th of March at the McKeown Road site and 0.52 m^3/sec at 5:10 am. Groundwater levels within the catchment did not show any response to rainfall over this period.

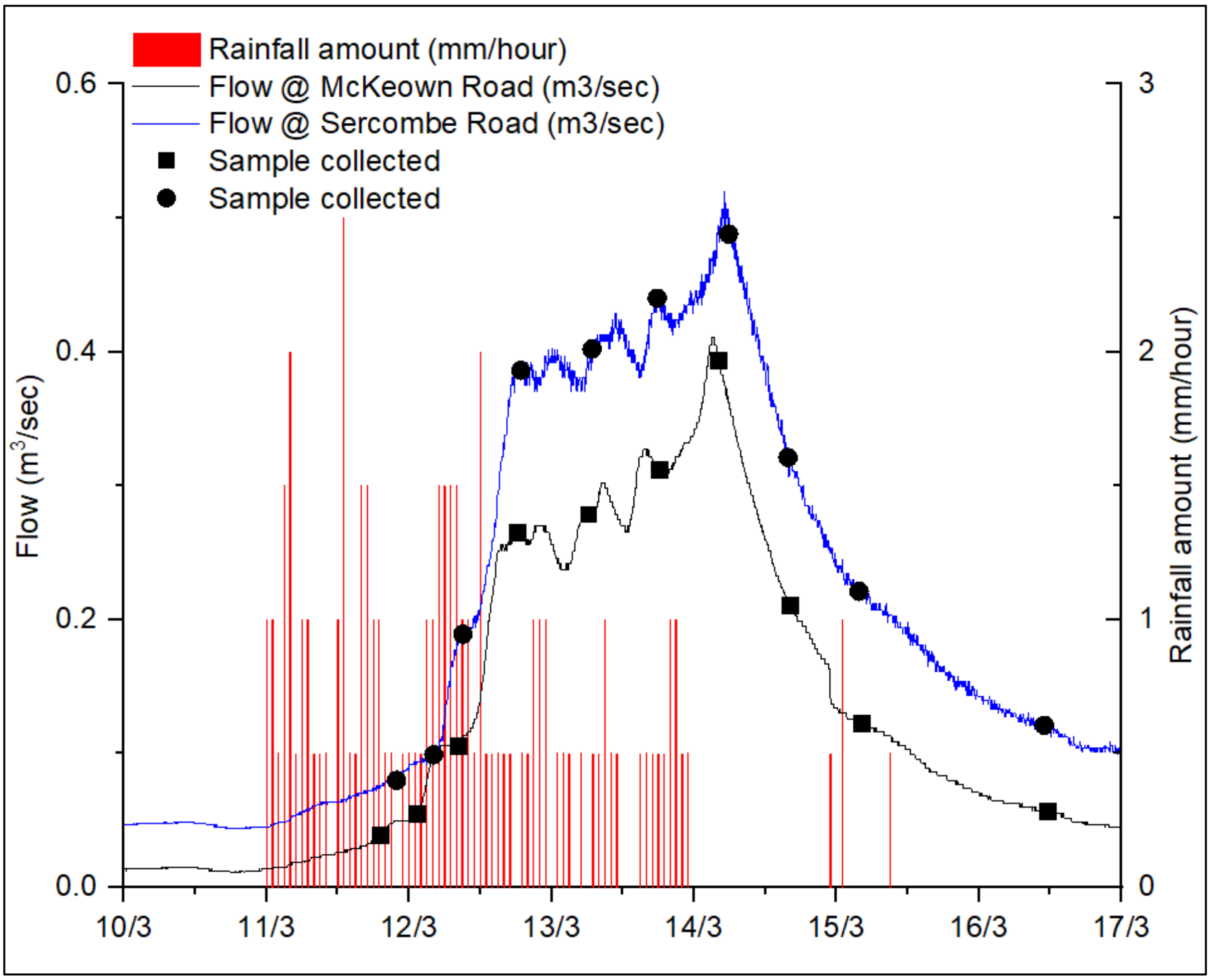

Figure 5-27: Barkers Creek flow response to rainfall Event 1

Nitrogen

All nitrogen species measured in Barkers Creek at McKeown Road (including ammonia-nitrogen and nitrite-nitrogen generally mirrored the hydrograph for this event, i.e. as flows increased so did nitrogen concentrations (Figure 5-28). There was a second peak in nitrogen approximately 24 hours after the first peak on 14 March. At Sercombe Road, nitrogen concentrations were far more stable across the event (Figure 5-29). Peak nitrogen concentrations occurred 24 hours after the peak in flow. There was minimal change in ammonia-nitrogen (generally below detection level) and nitrite-nitrogen concentrations across the event. Nitrate-nitrogen loads peaked at 1.9 kg/hour in Barkers Creek at McKeown Road and 2.5 kg/hour in Barkers Creek at Sercombe Road. These loads were even higher for Total nitrogen at 2.8 kg/hour and 3.7 kg/hour, respectively.

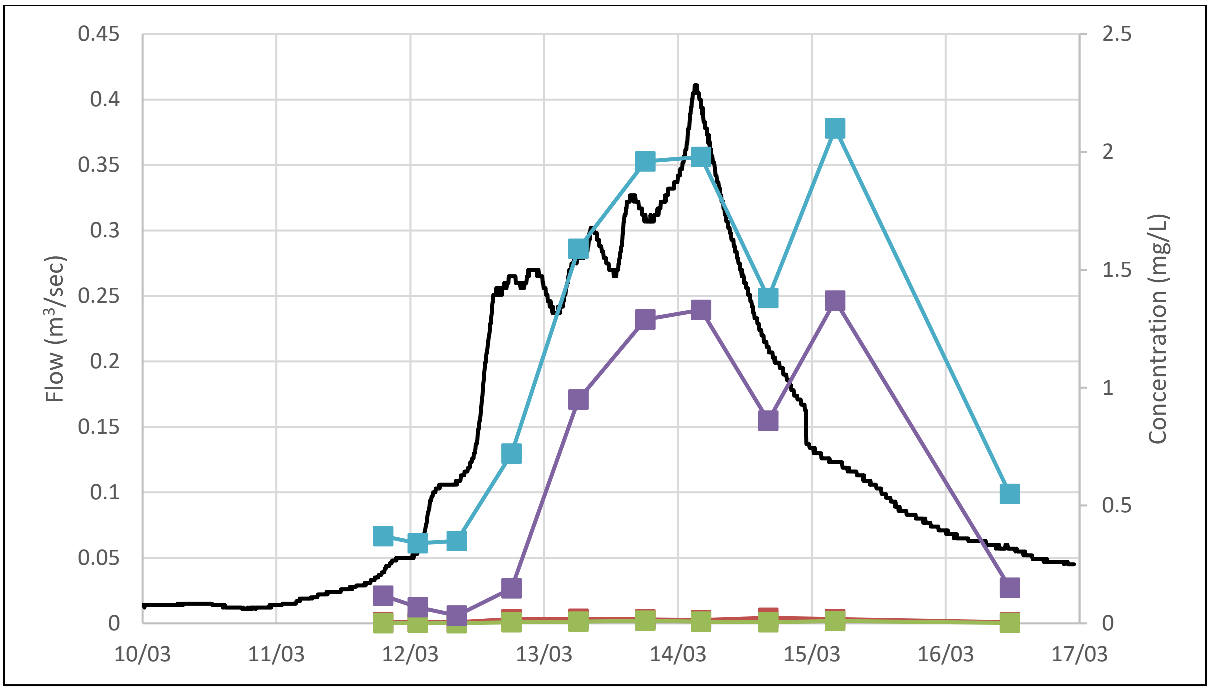

Figure 5-28: Nitrogen species concentrations in Barkers Creek during Event 1 at McKeown Road

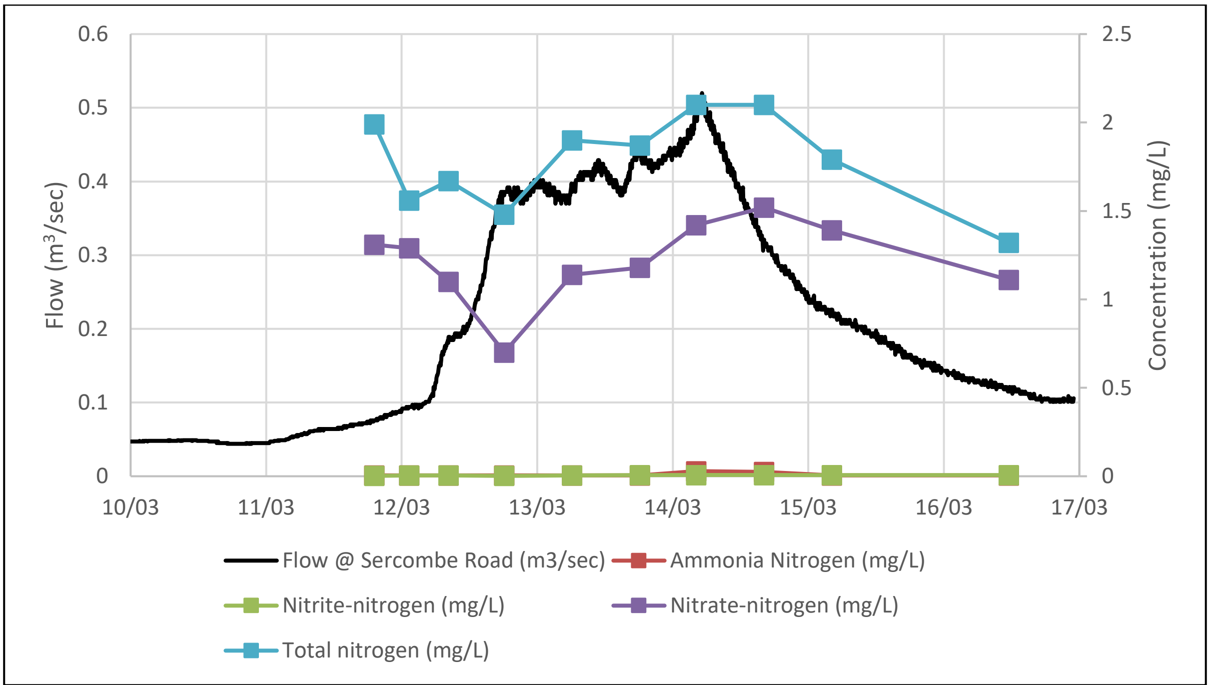

Figure 5-29: Nitrogen species concentrations in Barkers Creek during Event 1 at Sercombe Road

Phosphorus

Phosphorus measured in Barkers Creek at both McKeown Road and Sercombe Road generally mirrored the hydrograph for this event, i.e. as flows increased so did phosphorus concentrations (Figure 5-30 and Figure 5-31). Barkers Creek at McKeown Road had 2 peaks in total phosphorus concentrations over the event, the first being 10 hours before the peak in flow, and the second being 48 hours after the peak in flow. Barkers Creek at Sercombe reached peak total phosphorus early in the event, as flows began to stabilise at their high flow level. DRP concentrations behaved similarly through the event at both monitoring locations, peaking as the hydrograph stabilised at high flows and steadily decreasing for the remainder of the event. DRP loads peaked at 0.02 kg/hour in Barkers Creek at McKeown Road and 0.05 kg/hour in Barkers Creek at Sercombe Road. These loads were even higher for total phosphorus at 0.06 kg/hour and 0.17 kg/hour, respectively.

Sediment

TSS concentrations and turbidity measured in Barkers Creek at both McKeown Road and Sercombe Road, like phosphorus, generally mirrored the hydrograph for this event (Figure 5-32 and Figure 5-33). TSS concentrations and turbidity peaked, in Barkers Creek at both McKeown Road and Sercombe Road, as the hydrograph stabilised at high flows and progressively decreased over the remainder of the event. TSS loads peaked at 8.6 kg/hour in Barkers Creek at McKeown Road and 61 kg/hour in Barkers Creek at Sercombe Road.

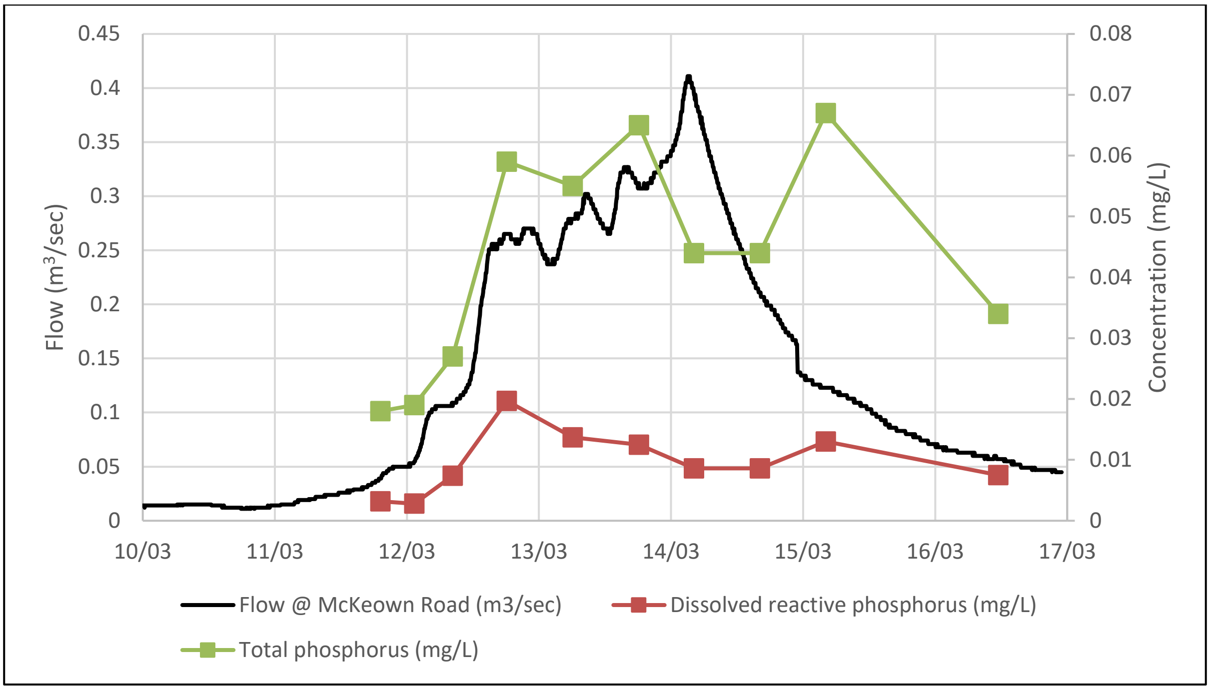

Figure 5-30: Phosphorus species concentrations in Barkers Creek during Event 1 at McKeown Road

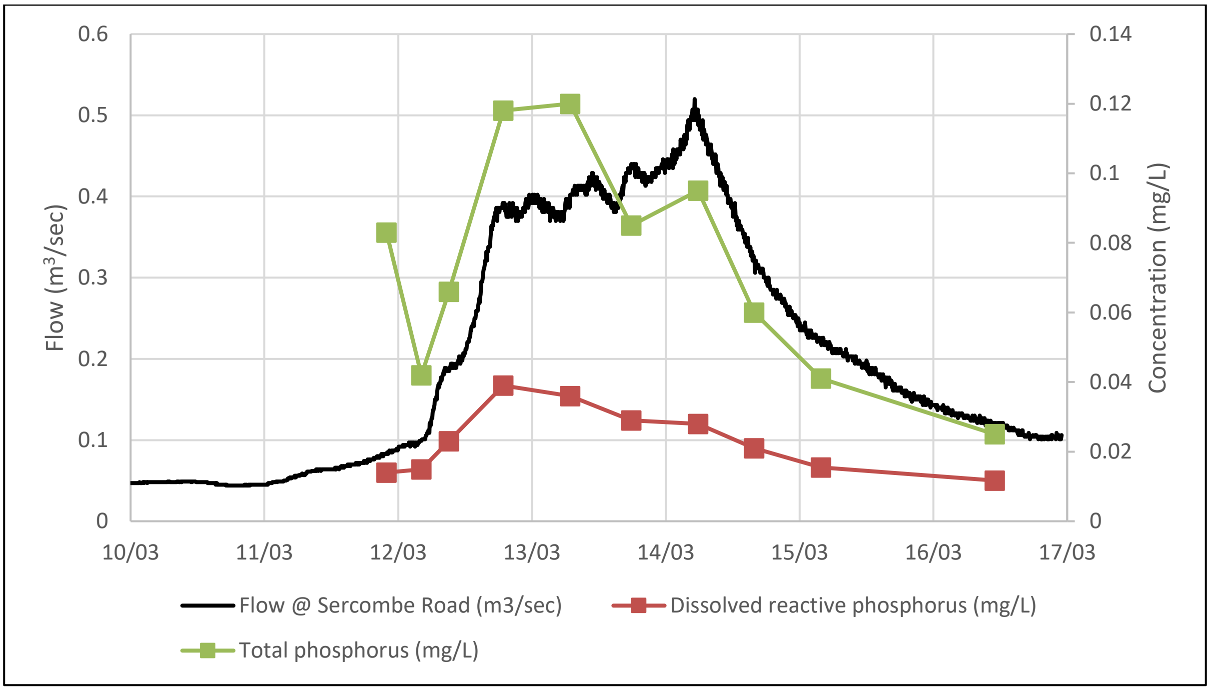

Figure 5-31: Phosphorus species concentrations in Barkers Creek during Event 1 at Sercombe Road

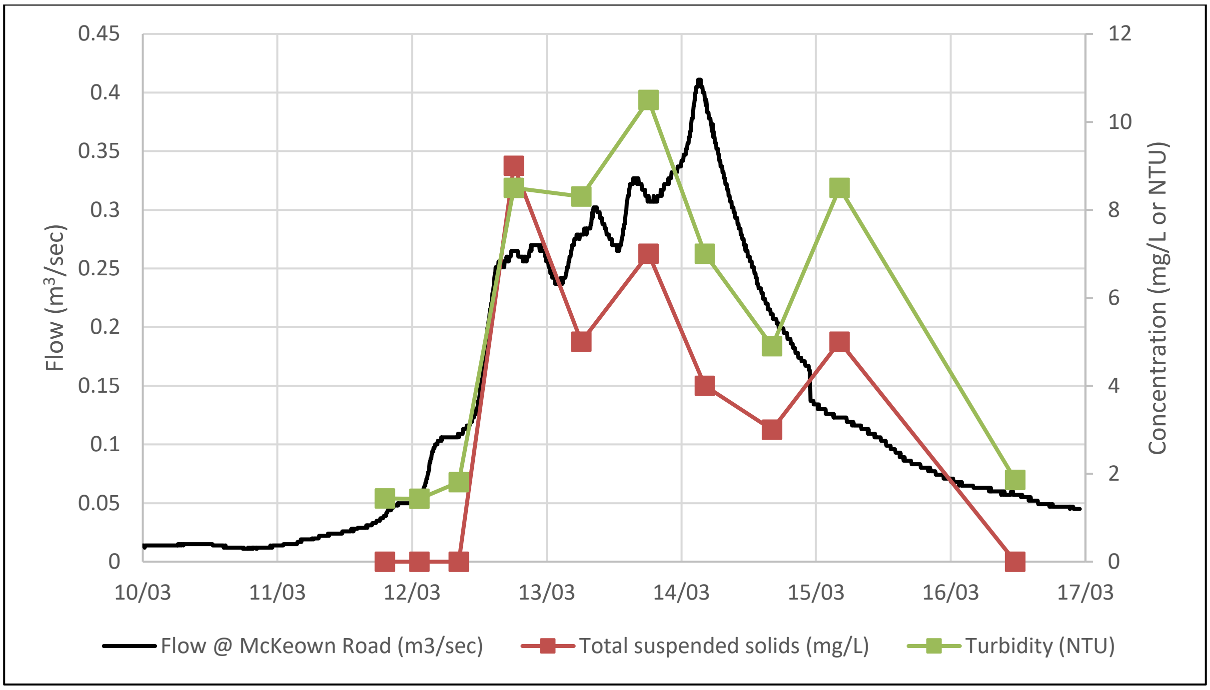

Figure 5-32: TSS concentrations and turbidity in Barkers Creek during Event 1 at McKeown Road

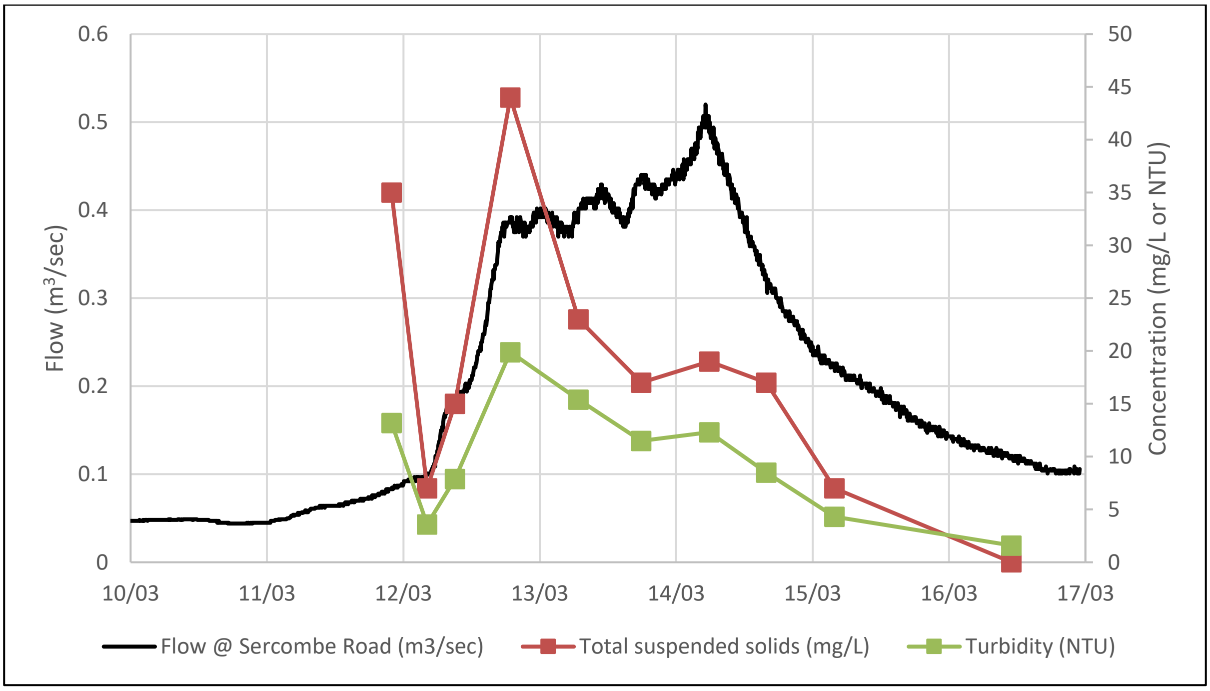

Figure 5-33: TSS concentrations and turbidity in Barkers Creek during Event 1 at Sercombe Road

5.4.2 Event 2 – April 2017

Event analysis occurred over a four day period from 12-16 April 2017. The total rainfall recorded at Environment Canterbury's Woodbury rainfall site over the four day period was 54 mm. Total rainfall over the Event was 2 mm more than Event 1. 37 mm was recorded over the 12th and 13th of April with a further 9.5 mm on the 14th April. Small rainfall amounts were also recorded on the 11th (3 mm) and 16th (14.5 mm). Hourly rainfall amounts were more variable than Event 1 and occurred predominantly in bursts of a few hours, peaking in intensity at 4 mm per hour. Flows reached their highest peak at 5.3 m^3/sec at 8:55 am on the 14th of April at the McKeown Road site and 7.1 m^3/sec at 9:25 am (Figure 5-34). Groundwater levels within the catchment did not show any response to rainfall over this period and were trending upwards at the time of Event 2.

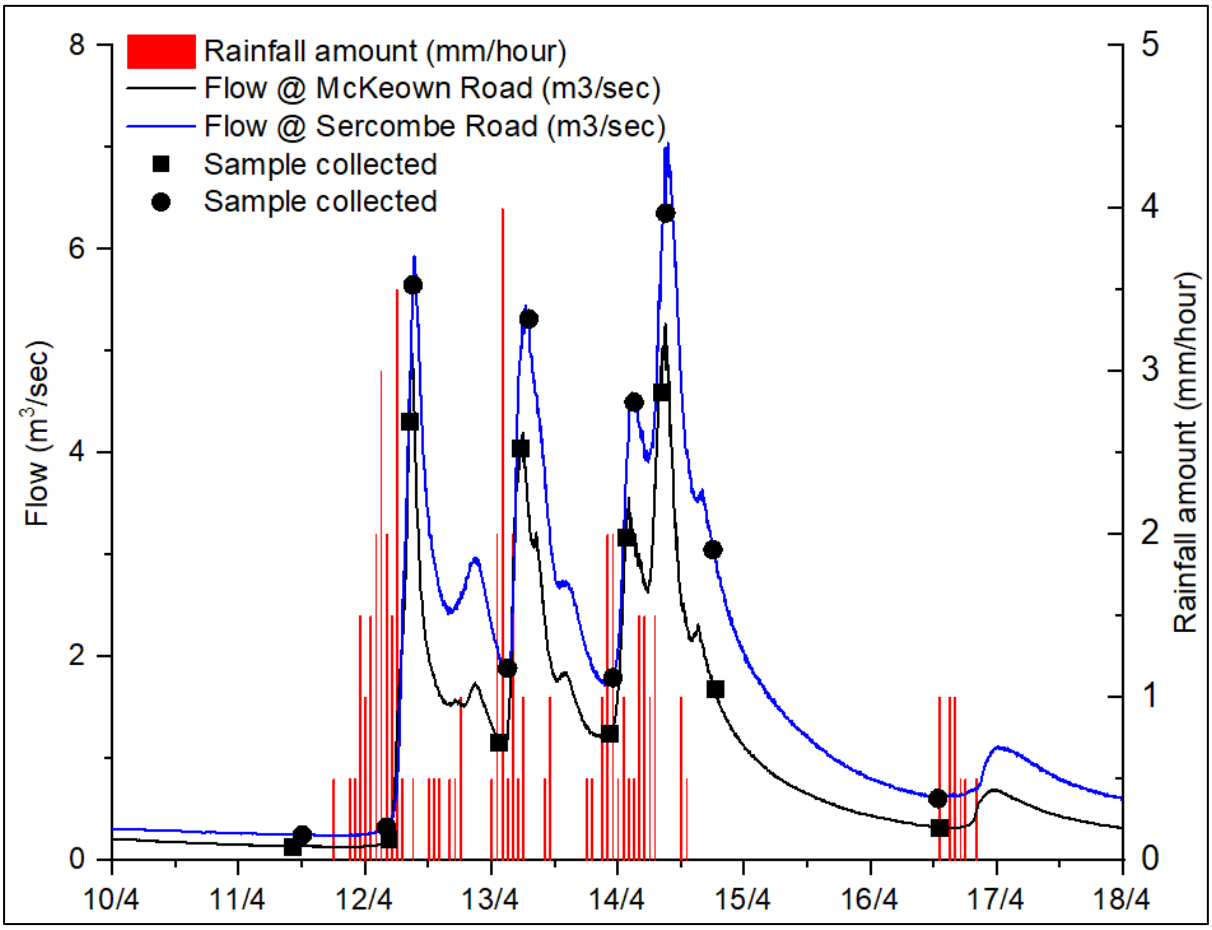

Figure 5-34: Barkers Creek flow response to rainfall Event 2

Nitrogen

In contrast to the results from Event 1, all nitrogen species measured in Barkers Creek at both sites (including ammonia-nitrogen and nitrite-nitrogen) were relatively stable across this event, (Figure 5-35 and Figure 5-36). Total nitrogen peaked during the first flow peak, and every flow peak thereafter. Nitrate-nitrogen had the opposite pattern, typically peaking during periods of lower flows. There was minimal change in ammonia-nitrogen (decrease over the high flow event) and nitrite-nitrogen (initial concentration increase then stabilised) concentrations across the event. Nitrate-nitrogen loads peaked at 14 kg/hour in Barkers Creek at McKeown Road and 23 kg/hour in Barkers Creek at Sercombe Road. These loads were even higher for Total nitrogen at 56 kg/hour and 83 kg/hour respectively.

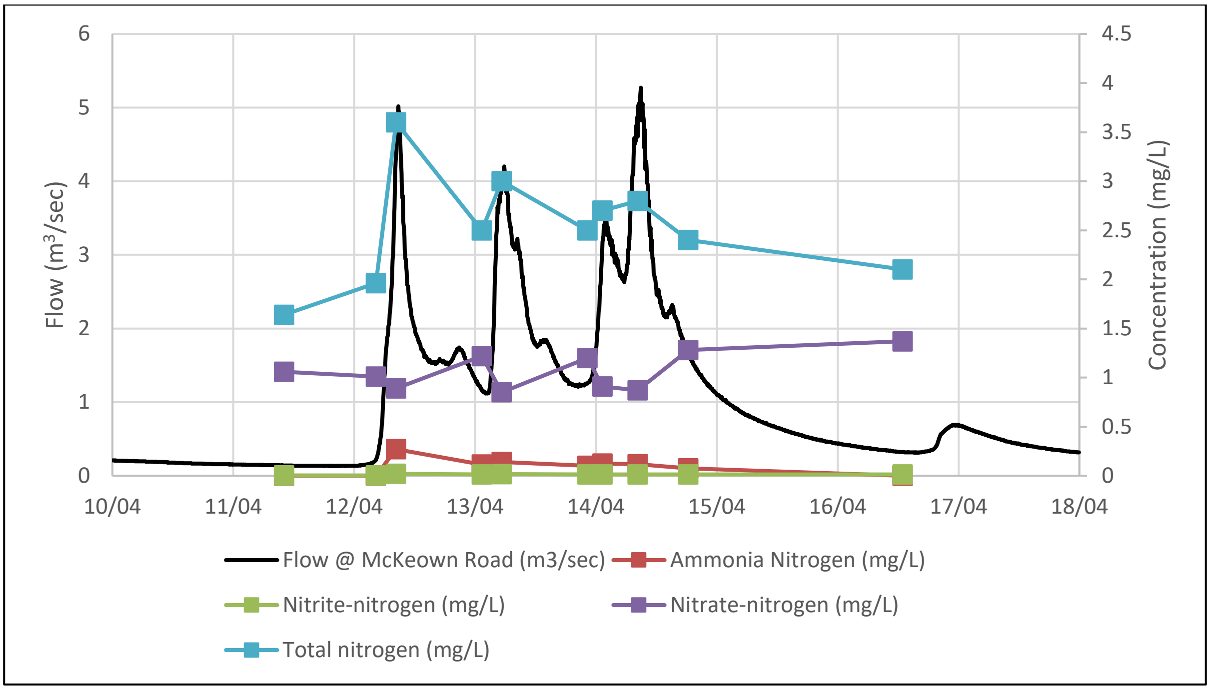

Figure 5-35: Nitrogen species concentrations in Barkers Creek during Event 2 at McKeown Road

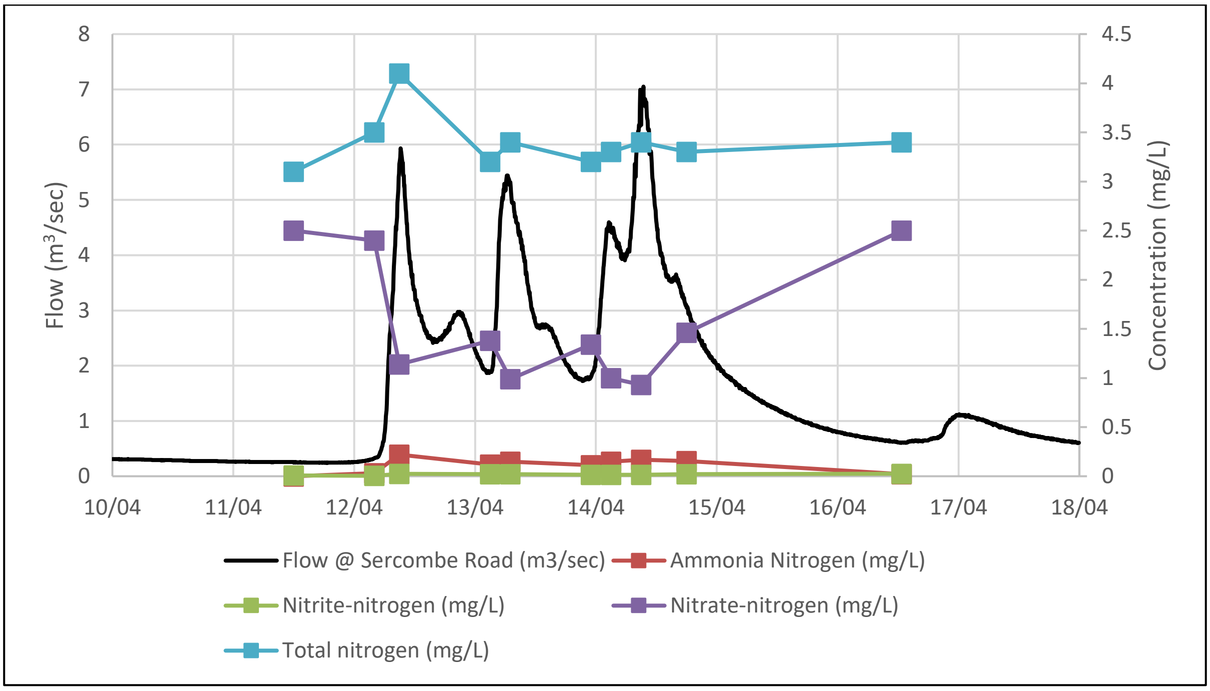

Figure 5-36: Nitrogen species concentrations in Barkers Creek during Event 2 at Sercombe Road

Phosphorus

Phosphorus measured in Barkers Creek at both McKeown Road and Sercombe Road generally mirrored the hydrograph for this event (Figure 5-37 and Figure 5-38). Barkers Creek at McKeown Road and Sercombe Road had 3 peaks in total phosphorus concentrations over the event, on each peak in flow periods shown on the hydrograph (maximum measured total phosphorus concentration was 0.5 mg/L at McKeown Road and 1.7 mg/L as Sercombe Road). DRP concentrations behaved similarly at both sites through the entire event. There was one exception at the Sercombe Road monitoring site where DRP (and total phosphorus) spiked upwards during the second flow peak from 0.2 mg/L to 1.3 mg/L. DRP loads peaked at 0.9 kg/hour in Barkers Creek at McKeown Road and 24.1 kg/hour in Barkers Creek at Sercombe Road. These loads were even higher for total phosphorus at 7.9 kg/hour and 32 kg/hour respectively.

Sediment

TSS concentrations and turbidity measured in Barkers Creek at both McKeown Road and Sercombe Road mirrored the hydrograph for this event (Figure 5-39 and Figure 5-40). TSS concentrations and turbidity peaked for the event, in Barkers Creek at both McKeown Road and Sercombe Road, during the first high flow peak. TSS loads peaked at 4.3 tonnes/hour in Barkers Creek at McKeown Road and 6.1 tonnes/hour in Barkers Creek at Sercombe Road.

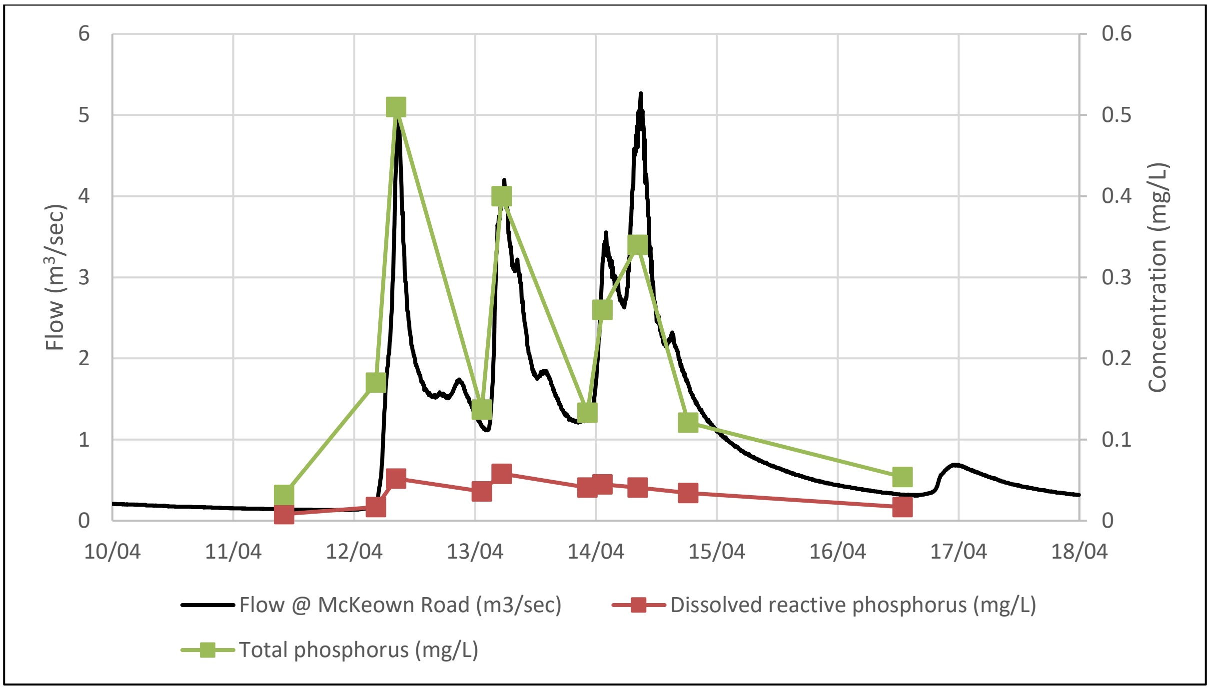

Figure 5-37: Phosphorus species concentrations in Barkers Creek during Event 2 at McKeown Road

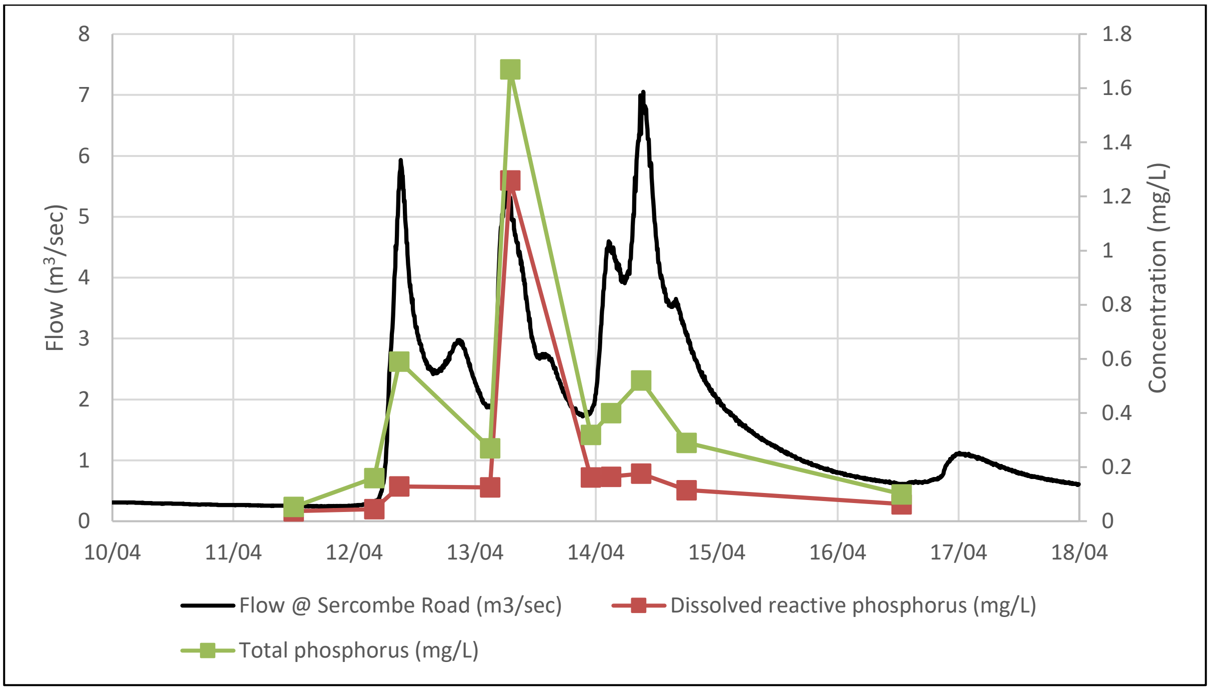

Figure 5-38: Phosphorus species concentrations in Barkers Creek during Event 2 at Sercombe Road

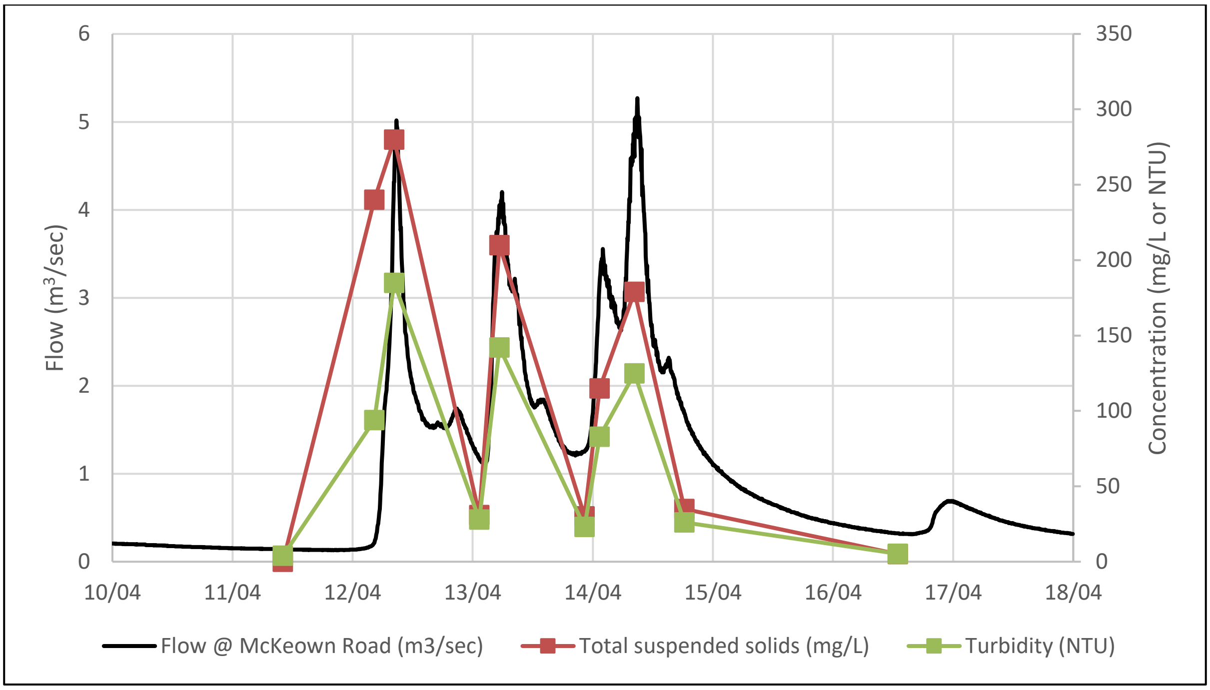

Figure 5-39: TSS concentrations and turbidity in Barkers Creek during Event 1 at McKeown Road

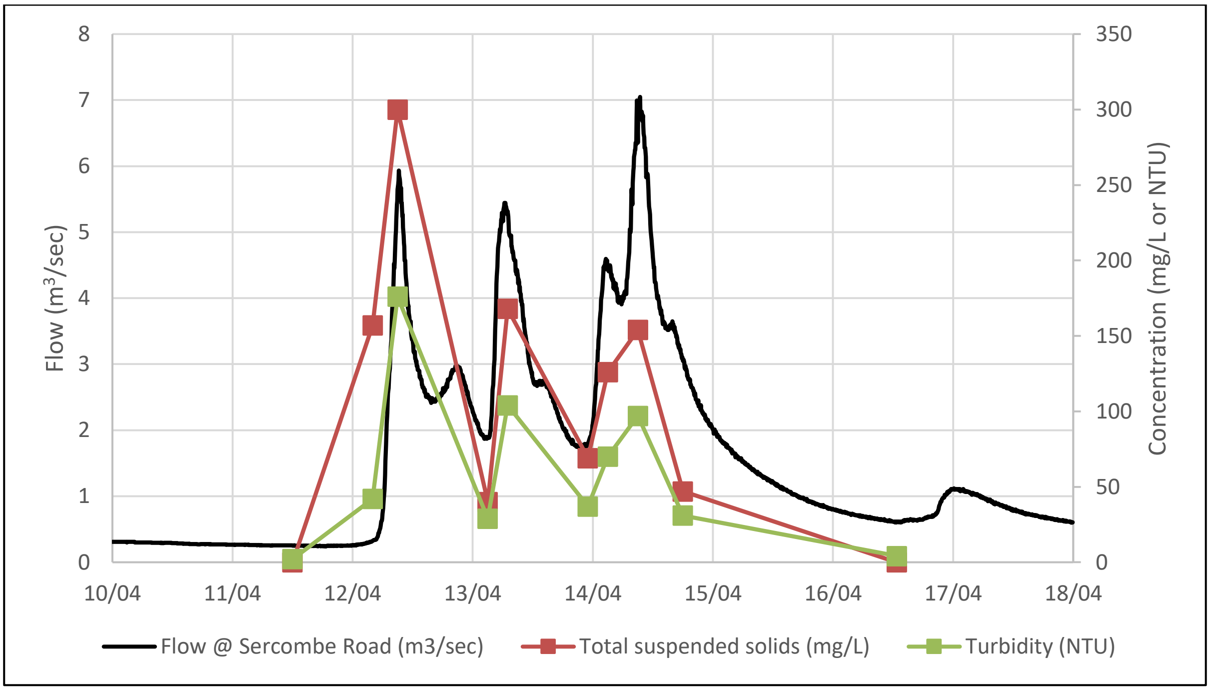

Figure 5-40: TSS concentrations and turbidity in Barkers Creek during Event 1 at Sercombe Road

5.4.3 Event 3 -July 2017

Event analysis occurred over a two day period from 21-22 July 2017. The total rainfall recorded at Environment Canterbury's Woodbury rainfall site over the two day period was 109.5 mm. 92 mm was recorded on 21 July with a further 17.5 mm on 22 July. Hourly rainfall amounts were much higher intensity than Event 1 and Event 2, with 83 mm occurring over the first 12 hours at a peak hourly rainfall intensity of 9.5 mm. Flows in Barkers Creek responded rapidly quickly reaching the peak flow for the event, peaking at 54 m^3/sec at 15:20 on the 21st of July at the McKeown Road site and 71 m^3/sec at 15:25 (Figure 5-41). During this event, Barkers Creek burst its bank in several places, and flooding within the catchment was extensive (Figure 5-42), suggesting flow may have been higher than what was recorded. Groundwater levels were trending upwards at the time of the rainfall event, and there is a noticeable gradient increase in the rising groundwater levels towards the end of the rainfall event (Figure 5-43).

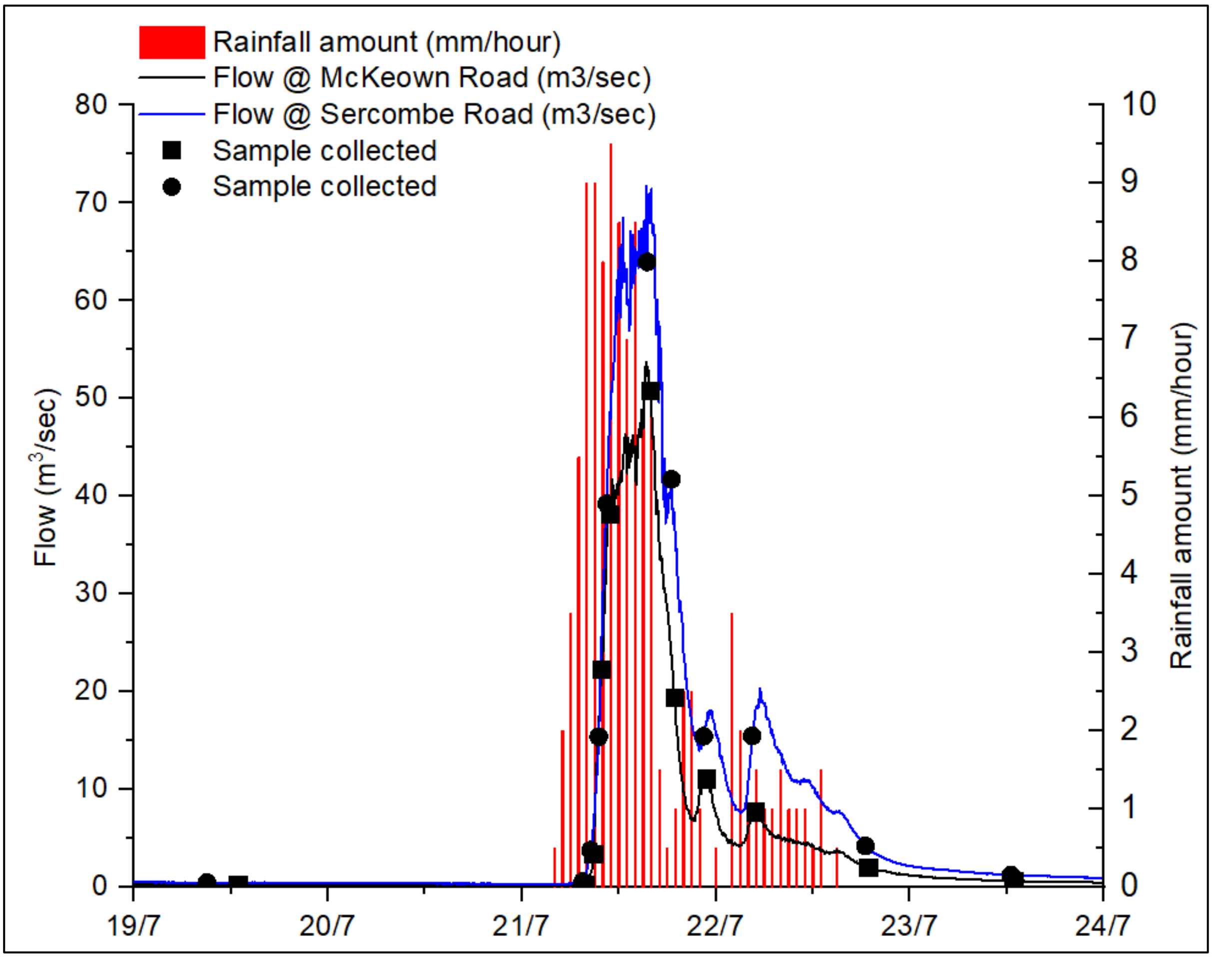

Figure 5-41: Barkers Creek flow response to rainfall Event 3

Figure 5-42: Photos of Barkers Creek catchment flooding during Event 3. Left: Barkers Creek looking upstream at Sercombe Road Bridge. Right: Barkers Creek looking upstream at McKeown Road Bridge. Note these are the approximate locations of baseflow photos presented in Figure 5-6

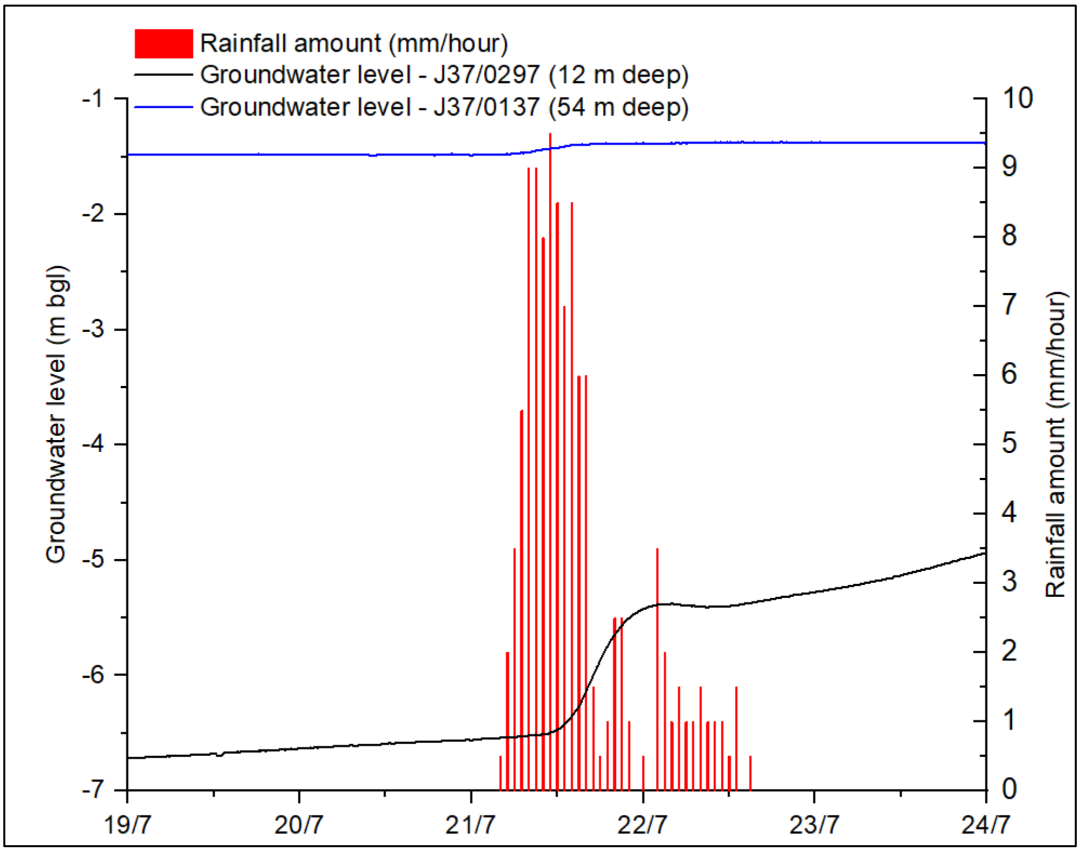

Figure 5-43: Groundwater level response to rainfall during Event 3

Nitrogen

All nitrogen species (except for nitrate-nitrogen) concentrations measured in Barkers Creek at both McKeown Road and Sercombe Road followed the pattern observed in the hydrograph, (Figure 5-44 and Figure 5-45). Total nitrogen peaked during the storm flow peak. In contrast to Event 1 nitrate-nitrogen had the opposite pattern, with concentrations having an inverse relationship with flow (i.e. as flow increase, nitrate-nitrogen concentrations decrease and as flows decrease, nitrate-nitrogen concentrations increase). Nitrate-nitrogen loads peaked at 0.09 tonnes/hour in Barkers Creek at McKeown Road and 0.1 tonnes/hour in Barkers Creek at Sercombe Road. These loads were even higher for Total nitrogen at 1.5 tonnes/hour and 1.7 tonnes/hour respectively. Nitrogen loads during Event 3 were significantly higher than during the other events monitored. The majority of nitrogen measured during peak flows were organic nitrogen rather than inorganic nitrogen species.

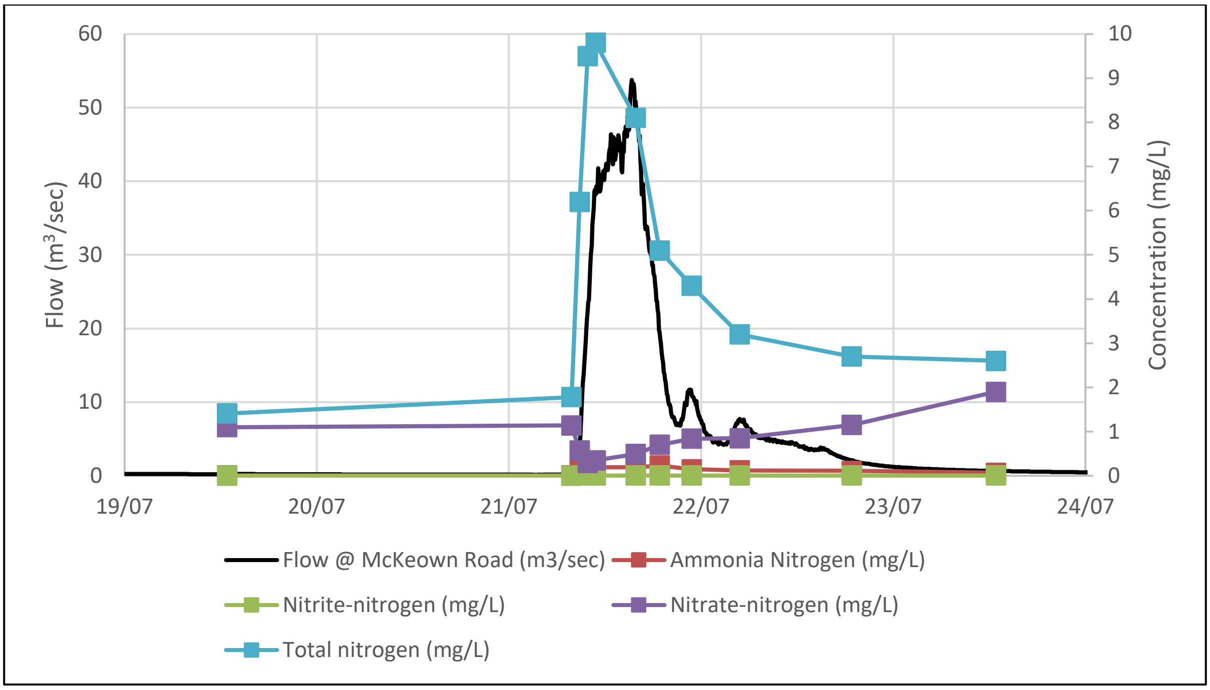

Figure 5-44: Nitrogen species concentrations in Barkers Creek during Event 3 at McKeown Road

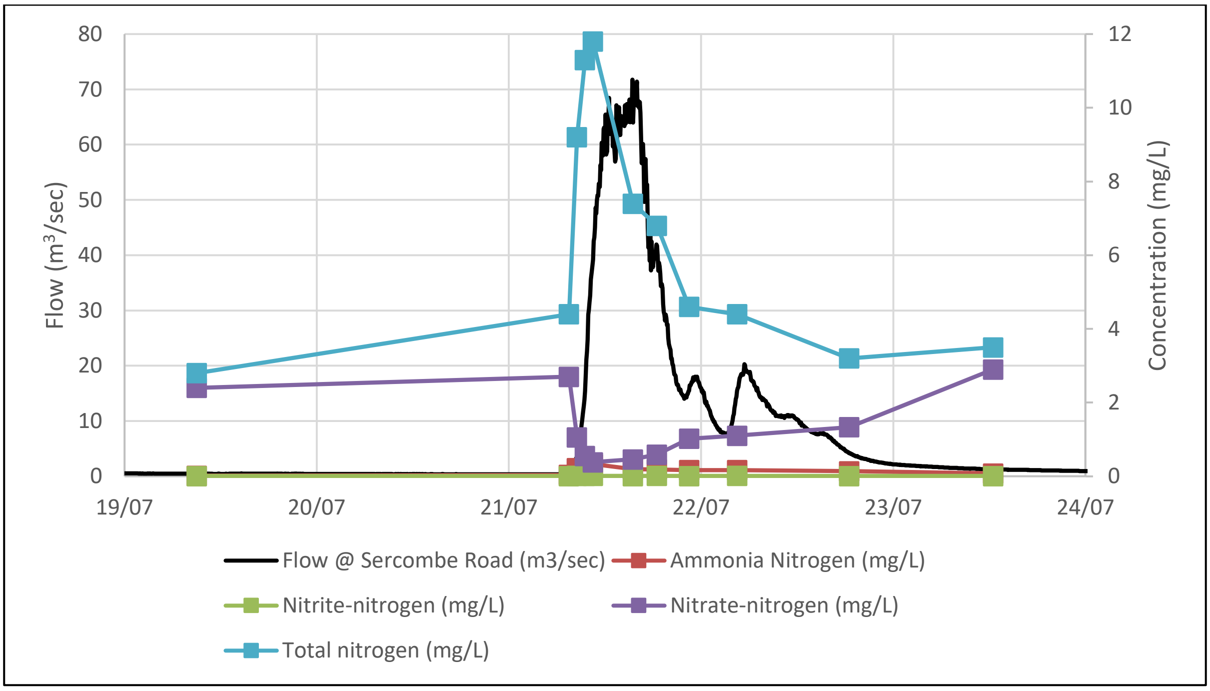

Figure 5-45: Nitrogen species concentrations in Barkers Creek during Event 3 at Sercombe Road

Phosphorus

Phosphorus (DRP and total phosphorus) measured in Barkers Creek at both McKeown Road and Sercombe Road generally mirrored the hydrograph for this event, peaking in concentration with peak flow (Figure 5-46 and Figure 5-47). DRP loads peaked at 6.4 kg/hour in Barkers Creek at McKeown Road and 14.7 kg/hour in Barkers Creek at Sercombe Road. These loads were even higher for total phosphorus at 567 kg/hour and 575 kg/hour respectively.

Sediment

TSS concentrations and turbidity measured in Barkers Creek at both McKeown Road and Sercombe Road mirrored the hydrograph for this event (Figure 5-48 and Figure 5-49). TSS loads peaked at 494 tonnes/hour in Barkers Creek at McKeown Road and 530 tonnes/hour in Barkers Creek at Sercombe Road.

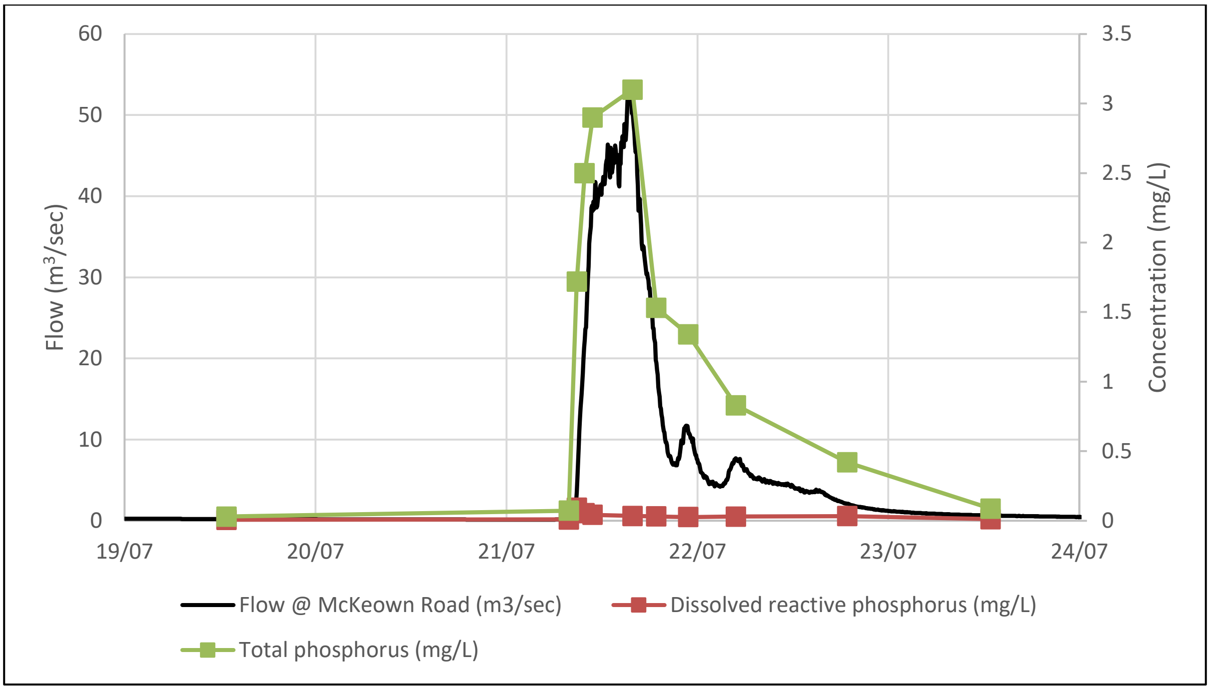

Figure 5-46: Phosphorus species concentrations in Barkers Creek during Event 3 at McKeown Road

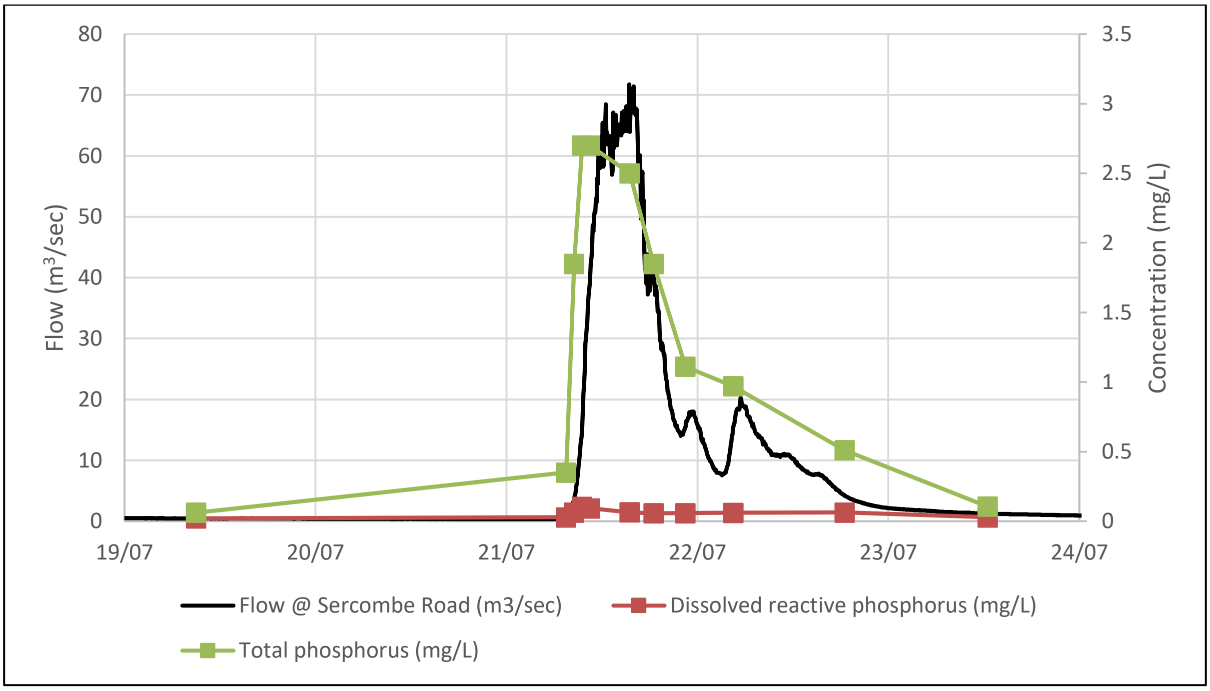

Figure 5-47: Phosphorus species concentrations in Barkers Creek during Event 3 at Sercombe Road

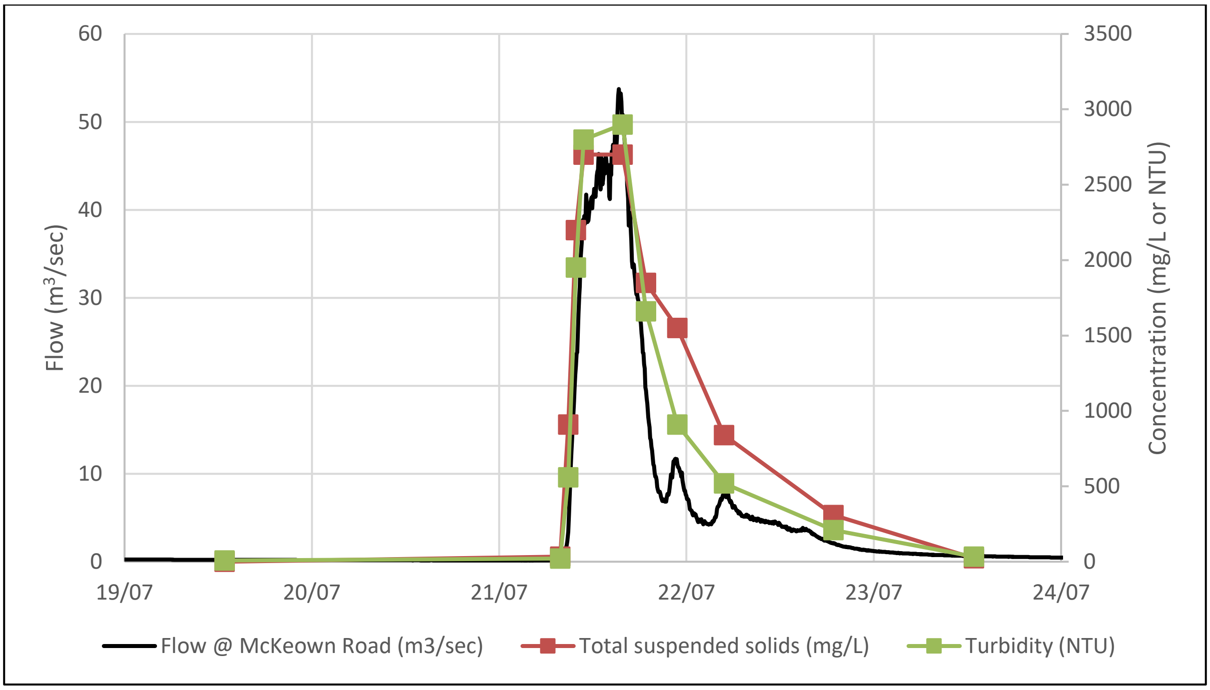

Figure 5-48: TSS concentrations and turbidity in Barkers Creek during Event 3 at McKeown Road

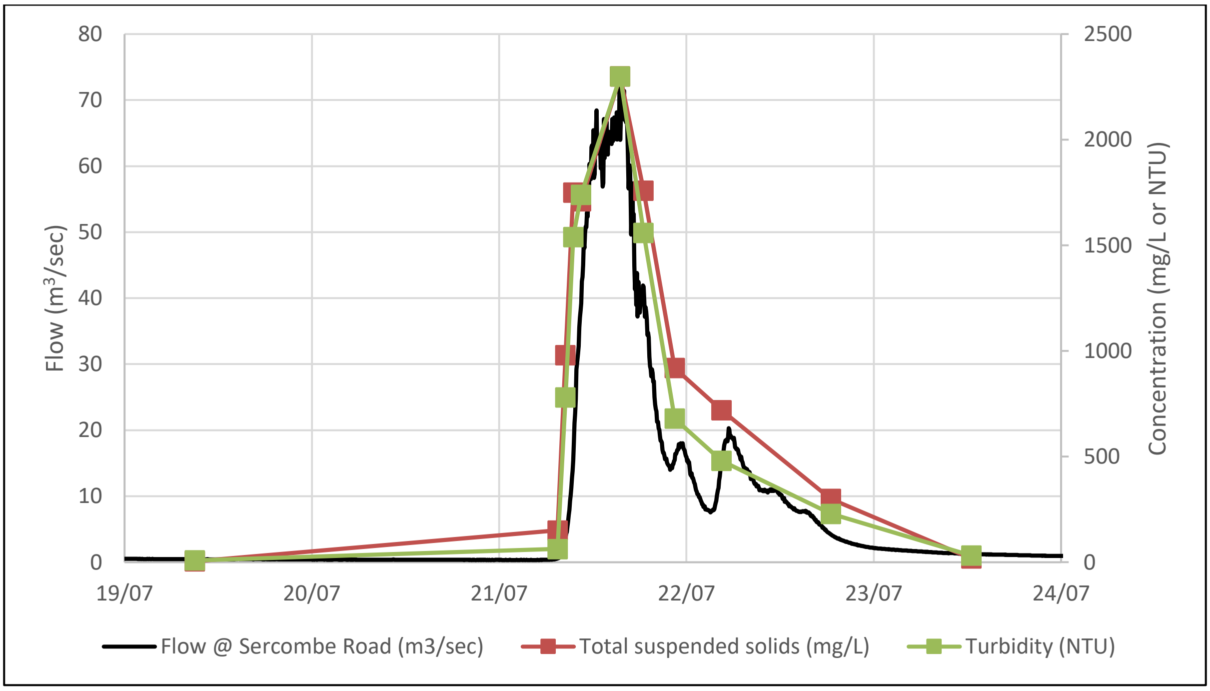

Figure 5-49: TSS concentrations and turbidity in Barkers Creek during Event 3 at Sercombe Road

6 Discussion

6.1 Hydrological and hydrogeological conditions

The Barkers Creek catchment functions like a basin. Inland of Tait Road it is constrained by the hill-fed upper Barkers Creek catchment. The upper catchment is rolling hill country and forms the northernmost extent of the South Canterbury Downlands. On the coastal side of Tait Road, the catchment is flat lying with old alluvial outwash covering much of the surface. To the north, the Kowai Formation outcrops create a northern boundary where they rise above the Quaternary alluvium. The Kowai Formation outcrops are at the surface due to faulting and folding which has created a northeast-southwest oriented anticline through the middle of the lower Barkers Creek catchment. The limited bore log data surrounding this area combined with surficial geology information suggests that old cover formation units are close to the surface. This appears to be limiting access to productive (greater than 5 l/s) aquifers throughout the Barkers Creek catchment, with most groundwater sourced from less than 20 m below ground level. In the south, the Geraldine Basalt rises above the Quaternary alluvium, influencing both groundwater and surface water flow. The basalt forms an impermeable barrier to flow. This basalt forces Barkers Creek and groundwater to flow in a west to east direction through to its confluence with the Waihi River.

The groundwater system and surface water system in the lower Barkers Creek catchment appear to be connected with interaction occurring between them. The flow gains and losses at all the surface flow gauging sites in Barkers Creek were consistent through low and high conditions. The groundwater system in the Barkers Creek catchment does not appear to fluctuate independent to the surface water system.

Rather, both the groundwater system and surface water system appear to be driven by rainfall. In addition, the surface water system (both Barkers Creek itself and the spring-fed drains), are influenced by groundwater seepage pathways which are, in part, an indirect rainfall recharge route. This pathway is slower than direct rainfall recharge to surface water and therefore the groundwater system generally has a more delayed response to rainfall compared with surface water, reflected in the groundwater hydrographs.

Surface flow in Barkers Creek shows a more immediate response to rainfall compared to groundwater. Surface flows typically rise rapidly, with peak levels and peak duration depending on rainfall intensity and duration. Unlike surface water, monitored groundwater typically did not show an immediate response to rainfall, except under high intensity/duration events (e.g. the rainfall event which occurred 21-22 July and saw 109.5 mm of rain fall). Instead groundwater responses were more cumulative, with increasing groundwater trends after wetter periods, and declining groundwater level trends after drier periods.

Groundwater flow systems are fundamentally dependent on local geological and geomorphological controls, which control the nature of the groundwater flow system (Toth, 1963). The groundwater system appears to behave as one, with the water table following topography through the lower catchment. This is reflected in the northeast to southwest groundwater flow direction across the lower Barkers Creek catchment (Figure 5-1). An exception to this is groundwater flow around the areas of Kowai Formation (older geology than the Quaternary alluvium covering much of the lower Barkers Creek catchment) in the lower catchment which have formed mounds above the plains. These older cover formations have been uplifted through faulting and folding over time (i.e. the anticline in the vicinity of the uplifted cover formations). These cover formations are expected to be acting as hydrogeological barriers. Available borelog information suggests these cover formations have a lower permeability due to an increased clay content. Groundwater flow is therefore expected to slow, and a portion potentially deviating around the mounds. In the lower catchment, one such cover formation mound (on the north side of Barkers Creek) has created a boundary forcing Barkers Creek to flow around it at which point the Geraldine basalt (on the south side of Barkers Creek) acts as a major geological boundary forcing groundwater in the Quaternary sediments and surface water (Barkers Creek and a spring-fed drain) to flow around it.

There is an upwards vertical hydraulic gradient in groundwater, especially in the lower Barkers Creek catchment as the geological constraints of the Geraldine Downs and anticline force groundwater to the surface. In the foothills of the upper catchment, upwards gradients reflect faulting which has created a pathway for groundwater to migrate from depth to the surface. While no data could be collected to confirm (due to no bores with groundwater level access), inland of McKeown Road there is expected to be downward gradients, reflecting groundwater recharge zones (and balancing the upwards gradients). In the lower Barkers Creek catchment, upwards vertical gradients in groundwater are reflecting a zone of groundwater convergence and discharge via the springs/spring-fed drains and baseflow in Barkers Creek itself.

Using piezometric contours, gaining/losing/neutral reaches can be identified. However due to the lack of groundwater levels able to be collected on the south side of Barkers

Creek, little information was able to be determined from the contours produced (Figure 5-1). The concurrent gauging identified two types of reaches in Barkers Creek, gaining and losing, highlighting the influence of groundwater on Barkers Creek. The reaches between McKeown Road and Saywell Ford (0.8 km), upstream Rokonui Drain and Middlemiss Road (0.8 km), and downstream Water Race to Barkers Creek confluence with the Waihi River (2.1 km), were all consistently gaining reaches through both high and low flow gaugings. The gain in flow between McKeown Road and Saywell Ford and Rokonui Drain to Middlemiss Road is probably due to the narrowing of the riparian margin related to the uplift of cover formation sediments (namely Kowai Formation). These sediments will be restricting groundwater flow, forcing some to the surface. The largest creek flow gains from groundwater occur along the reach between upstream Water Race and the Sercombe Road monitoring sites, with an average of 39 l/s (44% of flow) gained from groundwater along this reach. This is consistent with piezometric data and spring locations suggesting upwelling of groundwater and spring discharges towards the bottom of the lower catchment. The average total gain from groundwater between McKeown Road and Barkers Creeks confluence with the Waihi River is 48 l/s (44% of flow).

The reaches between Saywell Ford and upstream Rokonui Drain and Middlemiss Road and upstream Water Race were all consistently losing reaches through both high and low flow gauging's. The loss in surface flow to groundwater across both of these reaches is likely due to the widening of the riparian margin after being constrained by the uplifted cover formations (Kowai Formation for reach between Saywell Ford and Rokonui Drain, and both Kowai Formation and Geraldine Basalt between Middlemiss Road and Water Race). The largest creek flow losses to groundwater occur along the reach between Middlemiss Road and upstream Water Race monitoring sites, with an average of 6 l/s (19% of flow) lost to groundwater. While outside the focus of this study, Barkers Creek is expected to lose flow to groundwater in the upper catchment as it flows out of the foothills, providing a recharge source to groundwater.

As water flows through the groundwater system, chemical signatures of the surrounding geology and human influences are picked up by groundwater and can provide an indication of changes along a groundwater flow path. Water moving quickly through the catchment will have less contact time with sediment and less time undergo chemical transformations such as redox reactions, ion exchange/evolution and adsorption (Drever & Marion, 1998; Freeze & Cherry, 1979). This assumes a uniform geology throughout the catchment.

The low electrical conductivity in water across the Barkers Creek catchment suggests that flow paths/residence time between the recharge and discharge zones for groundwater are short. There is a general increase (albeit small) in conductivity between the upstream and downstream parts of the catchment. This reflects the time it takes for water to reach the bottom of the catchment and the interaction with sediment during this time. Electrical conductivity within the Barkers Creek catchment is on average 50% higher than what is observed in the Waihi River catchment to the north. This suggests that groundwater is older. Alternatively, it could be due to differences in geology and the lack of exposed greywacke basement rock. Despite suggestion that water is older than water in the Waihi River catchment to the north, actual ages are still expected to be relatively young. Alternatively, the higher electrical conductivity compared to the Waihi River catchment, and the increase in electrical conductivity between the upstream and downstream parts of the catchment could be reflecting land use practices which have the potential to increase electrical conductivity through pollution inputs. Future research in this catchment would be aided by age dating of water.

The composition of Barkers Creek water differs somewhat and has higher dissolved ion concentrations from that of the Waihi River. This is reflected in cluster B3 of the HCA (see Section 5.2.2). It is possible the older surficial geology, cover formations, loess and older Quaternary alluvium (Q2, Q4, Q6 and mQa), in the upper Barkers Creek catchment contribute this difference. These older sediments contain more weathered greywacke (and therefore increase clay content) which increase rock-water interactions and more geochemical dissolution potential. This is consistent with the hypothesised source of water to the Waihi River north of Geraldine identified by Burbery and Ritson (2010).

The composition of groundwater in the Barkers Creek catchment can be split into two categories. The first being groundwater with a mixed/anoxic redox state reflected in the elevated iron, magnesium, manganese and generally low dissolved oxygen concentrations (cluster A1 in the HCA). This groundwater signature is likely reflecting older (more evolved) water that has interacted with cover formation geology. The second groundwater category is reflecting shallower and more oxic groundwater conditions with high nitrate-nitrogen concentrations. This signature is showing anthropogenic influence on the groundwater system and the impact that land use is having.

Some groundwater in the Barkers Creek catchment has a signature similar to that of surface water and groundwater in the Waihi River catchment (cluster B3). This could indicate a component of recharge to the groundwater system comes from the Waihi River catchment. The Waihi River is known to lose surface flow along its upper reaches (Scarf, 2003), and so there is potential that a component of this is flowing into the Barkers Creek catchment at depth. This water has a lower chloride signature (cluster B3), which could be reflecting less dominant coastal rainfall influences and more dominant north-west rainfall influences. The Waihi River catchment extends further to the north and into the foothills, giving weight to this. While there is uncertainty in the piezometric contours in the upper catchment, they do not discount the potential for groundwater transfer between the Waihi River and Barkers Creek catchment

Water in the Barkers Creek catchment is dominated by calcium and bicarbonate, which indicates that recharge from surface water and rainfall has interacted with local geology. The Ca-HCO_3 signature is typical of Canterbury groundwater (Burbery & Ritson, 2010; Burbery & Vincent, 2009) and is a reflection of calcite dissolution in greywacke basement sediments and HCO_3 from soil respiration. Calcite easily weathers compared to the more dominant sodium-feldspar present in the sediments, giving water the dominant Ca-HCO_3 signature (Jacobson et al., 2003).

Water samples from four sites (two groundwater and two surface water) exhibits a Na-HCO_3 signature within the Barkers Creek catchment. The two groundwater sites are both deeper bores[14] and the Na-HCO_3 signature in these bores is possible a

[14] BY19/0013 is screened from 37-52 m and J37/0202 is screened from 58.66-62.66 m.

reflection of groundwater interaction with cover formation sediments (i.e. groundwater that is older and has had more time to interact with sediments) and LSR. The two surface water sites with Na-HCO_3 signatures are the two spring-fed drains feeding into Barkers Creek. SQ36223 is fed by a number of springs and drains emanating within basalt outcrops to the south of Barkers Creek. The Na-HCO_3 signature is likely a reflection of less dominant carbonate dissolution (due to minimal carbonate sources) and more influence by coastal rainfall (NaCl signature). The other site with a Na-HCO_3 is a drain nearest to the Barkers Creek/Waihi River confluence (SQ36224). This drain has a large catchment area at the bottom of the catchment and where groundwater is upwelling and discharging to surface water. The Na-HCO_3 signature at this spring-fed drain is likely a reflection of anthropogenic inputs (reflected in the elevated nitrate-nitrogen concentrations at times). At SQ36224 there is also expected to be a component of upwelling of deep groundwater which is anoxic (causing denitrification to occur) which has a Na-HCO_3 signature. Alternatively, the Na-HCO_3 signature at these four sites could be reflecting the breakdown of sodium-feldspar which, with quartz, makes up 90% of the basement rock composition in the region (Andrews et al., 1976; Raeside, 1964). While calcite weathers more easily, the sodium-feldspar will be contributing to the sodium signature present in water in the catchment.

6.2 Distribution of contaminants of concern

Nitrate-nitrogen concentrations are typically higher in groundwater than what is observed in Barkers Creek. In groundwater, nitrate-nitrogen concentrations decrease with depth. This could be occurring for two reasons. The first reason for low nitrate-nitrogen concentrations in deep groundwater is that the recharge zone and flow paths for water getting to this depth is in the upper catchment, where land use is generally less intensive and nitrate-nitrogen concentrations are low in both groundwater and

Barkers Creek itself. This low nitrate-nitrogen pattern is likely reflecting older groundwater. Age dating analysis of groundwater would help to verify the driver for this. The second possible reason is that groundwater sourced from deeper than 30 m typically has a mixed redox state. Denitrification occurs under anoxic conditions, reducing nitrogen concentrations in groundwater and acting as a natural sink for nitrate-nitrogen.

A mass balance was undertaken to understand the relative contributions of nitrate-nitrogen to Barkers Creek from groundwater and the spring-fed drains (i.e. pathways). This also assisted in identifying hot spot areas. This mass balance assessment was undertaken using bimonthly gauging and concentration data, as this was the highest resolution data available for all sites. These data would then be used to provide an estimate for annual nutrient export from Barkers Creek. While the annual load figure will have high potential error, it is the percentages that are most useful in understanding the relative weighting of inputs and outputs compared to loads in the Waihi River. With the inputs (Barkers Creek at McKeown Road and the spring-fed drains) and the output (Barkers Creek upstream of confluence with Waihi River) the balance can be assumed to be from groundwater.

Under baseflow conditions, nitrate-nitrogen loads in Barkers Creek are relatively stable (small increases and decreases in load) up until the Barkers Creek upstream Water Race (3.1 km from confluence with Waihi River) monitoring site. From this site there is an increase in nitrate-nitrogen load, through to the Barkers Creek confluence with the Waihi River. This increase is attributable to groundwater seepage. On the basis of the sampling run on 19/7/2017, under higher flow conditions the nitrate-nitrogen loads appear to be more variable, reflecting variation in groundwater seepage into Barkers Creek along the reach. 20% (based off the six bimonthly sampling runs undertaken for this study) of the annual nitrate-nitrogen load from groundwater between Barkers Creek at McKeown Road and Barkers Creeks confluence with the Waihi River is from groundwater. This equated to 10.8 tonnes (of the 54 tonne annual estimate) of total nitrate-nitrogen load exported via Barkers Creek to the Waihi River. Of the total annual nitrate-nitrogen load exported via Barkers Creek to the Waihi River 11% (5.9 tonnes) is from the Barkers Creek catchment above McKeown Road. The remaining 69% of the apparent nitrate-nitrogen load from the catchment can be attributed to the lower Barkers Creek catchment, exported via the spring-fed drains.

The mass balance shows the relative nitrate-nitrogen load contribution of Barkers Creek above McKeown Road, the spring-fed drains below McKeown Road and groundwater during the six concurrent gauging and sampling runs and a crude annual estimate from these averages. The naturalised mass balances undertaken for the 9/11/2016, 17/1/2017 and 21/3/2017 gauging and sampling runs did not match export from Barkers Creek to the Waihi River. Through each of the gauging runs, several visual estimates had to be made to assess flow, as the flow was either not sufficient enough, or the channel was not wide enough to take measurements using the flowtracker. A conservative error estimate on these visual gaugings is 50% which is significant compared to the 2-4% error estimate on gaugings made using the flowtracker. Sensitivity analysis on the visual gaugings using a potential error of 50% resulted in the three mass balances being able to be balanced. In addition biological growths such as periphyton has the potential to uptake nitrogen (including nitrate-nitrogen) in stream (Heathwaite, 1993). The imbalance in nitrogen is a combination of factors between the potential visual gauging error and instream uptake through periphyton.

The majority of nitrate-nitrogen load exported (69%) from Barkers Creek to the Waihi River originates from the spring fed drains. Of these spring-fed drains, over half (56%) of the 69% comes from D4 (9.4%), D10 (35.5%) and D11 (10.7%; Figure 6-1). The sub-catchments that these three spring-fed drains drain are intensively farmed by dairy, sheep and beef, dairy grazing and some arable cropping practices. Groundwater seepage to Barkers Creek is the other significant contributor to nitrate-nitrogen load, contributing 20% of the total load in Barkers Creek. Groundwater and the three spring-fed drains are the key nitrogen hotspots in Barkers Creek, cumulatively contributing 75% of the load exported to the Waihi River. They are the key contributors to nitrate-nitrogen load exported via Barkers Creek to the Waihi River. A breakdown of the relative load comparison is shown spatially in Figure 6-1. These loads have been broken down to a spring-fed drain sub-catchment scale for display. The actual catchments for these spring-fed drains will be much greater. This is because they are groundwater fed, and therefore not just a reflection of the surface water catchment, but also a cumulative load from up-gradient groundwater intercepting the spring-fed drain.

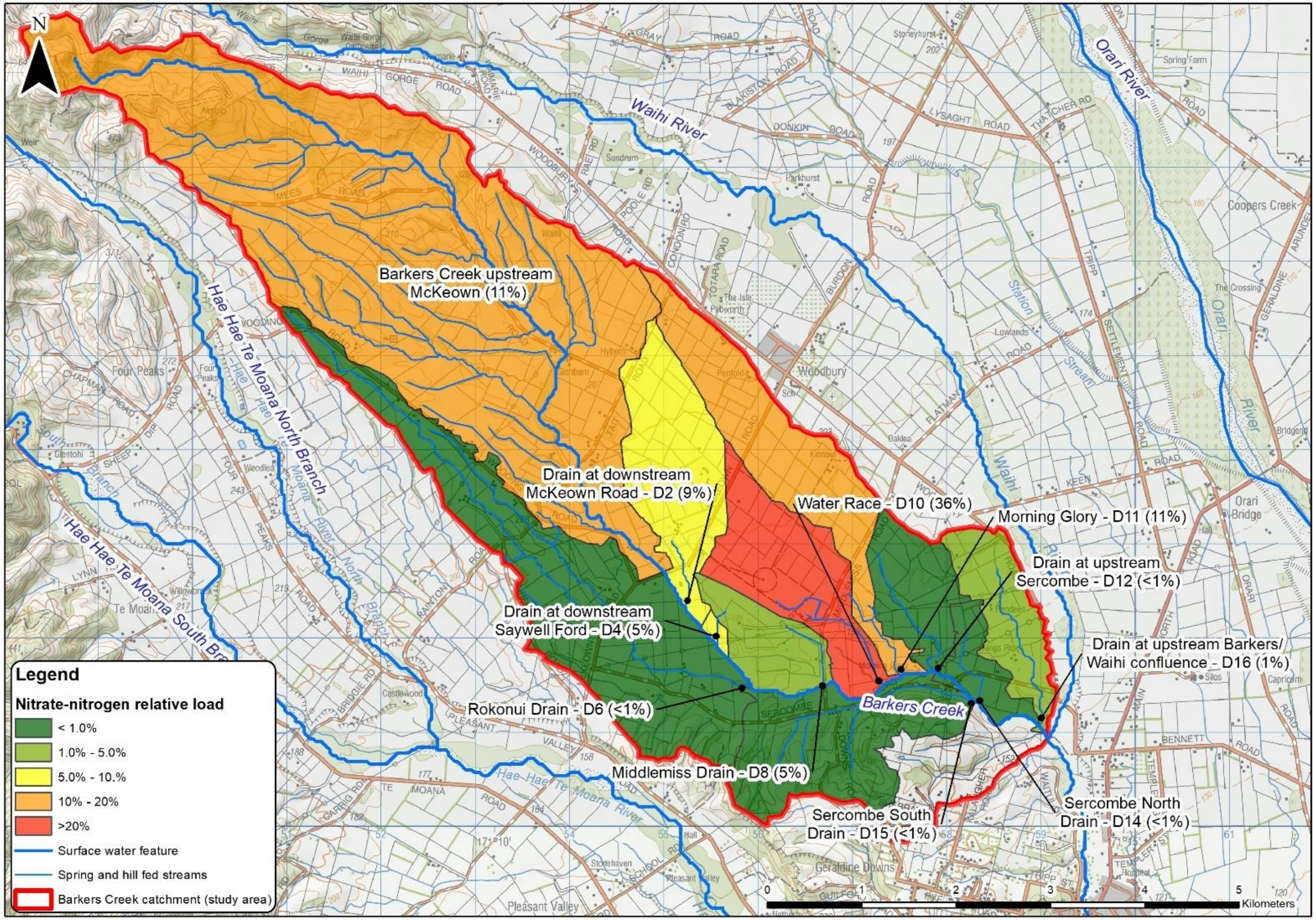

Figure 6-1: Nitrate-nitrogen effective source zones in the Barkers Creek catchment

Like nitrate-nitrogen, DRP concentrations are typically higher in groundwater than in Barkers Creek. Concentrations of DRP are also higher in the spring-fed drains compared to Barkers Creek. In groundwater, DRP concentrations are independent of depth, with variable concentrations across all depth intervals. The presence of elevated DRP concentrations at depth likely reflects a natural phosphorus source in the aquifer sediments. The spring-fed drain (D6) with excessive (greater than 0.03 mg/L) DRP concentrations has a large catchment area, much of which is unfenced allowing stock access. This stock access stirs up sediment and mobilises phosphorus that is sorbed to the sediment. D6 also had sediment export occurring during each of the six sampling runs with a daily TSS export of between 1 kg and 17 kg. Given phosphorus typically adsorbs to sediment (Domagalski & Johnson, 2011), the high DRP load in D6 The other spring-fed drains all had consistent DRP concentrations across the 12 month monitoring period, reflecting their groundwater fed nature. In the main stem of Barkers Creek, there is an increase in DRP concentrations between McKeown Road, and its confluence with the Waihi River. This is consistent with the fact that Barkers Creek is fed by 10 spring-fed (groundwater-fed) drains below McKeown Road, which carry significant concentrations of DRP and to a lesser degree groundwater seepage through the stream bed.

Under baseflow conditions, little sediment is exported out of the Barkers Creek catchment. Six of 26 sampling runs had measurable TSS concentrations with a daily export range of between 7 kg and 42 kg across these runs. Under these baseflow conditions Barkers Creek appears to act as a sediment sink, with all drains having at least two samples with TSS load export into Barkers Creek (minimum daily load of 0.3 kg and maximum daily load of 75 kg). In the Waihi River upstream of the confluence with Barkers Creek, no sediment was recorded in any of the 26 samples collected. This is consistent with the pattern in DRP (i.e. drains carry high loads relative to what is exported from the catchment). The adsorption of phosphorus to sediment is the likely reason behind this pattern. While no samples were collected in the Waihi River during storm events, anecdotal evidence suggests Barkers Creek carrier higher TSS loads during storm events compared to the Waihi River. This is reflected in a photograph taken at the confluence of Barkers Creek and the Waihi River during the final recession of Event 2

Figure 6-2: Photo of Barkers Creek (left) confluence with the Waihi River (right) during flow recession of Event 2

Similar to nitrate-nitrogen results, DRP loads in Barkers Creek are relatively consistent (small increases and decreases in load) in the reaches upstream of Barkers Creek at

Rokonui confluence downstream. From this site there is a decrease in DRP load, through to Barkers Creeks at Middlemiss Road. From this site, D6 carries a significant DRP load to Barkers Creek making a decreasing load counterintuitive. However, this reach is also a gaining reach so it is probable that groundwater is having a diluting effect to DRP loads along this reach. From Middlemiss Road, Barkers Creek on generally gains in DRP load through to its confluence with the Waihi River. The mass balance shows that the DRP load from groundwater between Barkers Creek at McKeown Road and Barkers Creeks confluence with the Waihi River is minimal, with all of the load exported from Barkers Creek to the Waihi River attributable to the spring-fed drains. Only during flow above baseflow did Barkers Creek show a gain in DRP load from groundwater. On 19/7/2017 the DRP load to Barkers Creek from groundwater was 0.37 kg/day (39.5% of the total catchment load on that day). This sampling run was undertaken during the later stages of a recession curve and there was an increased gain in flow from groundwater on this day. Given the rain that fell in the weeks preceding this monitoring run, shallow groundwater at the water table is expected to be carrying an increased DRP load due to rainfall recharge through the vadose zone mobilising phosphorus into the groundwater system. The lack of apparent DRP load from groundwater suggests that DRP is a surface water and TSS issue, rather than groundwater.

Of the total annual DRP load exported via Barkers Creek to the Waihi River, 13% is from the Barkers Creek catchment above McKeown Road. This is similar to the nitrate-nitrogen load pattern which saw 11% exported from the same sub-catchment. There remaining 87% of total load exported from Barkers Creek to the Waihi River is sourced from the spring-fed drains below Barkers Creek at McKeown Road. These spring-fed drains contribute more DRP to Barkers Creek than what is exported from Barkers Creek to the Waihi River under baseflow conditions. Phosphorus typically adsorbs to sediment (Domagalski & Johnson, 2011), and this is reflected in the imbalance of DRP across the catchment under baseflow conditions where there is not expected to be additional inputs unaccounted for. Under baseflow conditions, phosphorus binds to the sediment and accumulates.

The mass balance produced shows the relative DRP contribution of Barkers Creek above McKeown Road, the spring-fed drains to Barkers Creek below McKeown Road and groundwater during the six concurrent gauging and sampling runs. The mass balances undertaken for the for all balance points, except the 19/7/2017 gauging and sampling run did equate to the load exported from the catchment on those days. While visual gauging estimates will be again providing a level of error, sensitivity analysis did not assist in solving the imbalance. While imbalanced, the mass balance does show that the spring-fed drains are contributing significant loads of DRP to Barkers Creek.

The majority of DRP load exported from Barkers Creek to the Waihi River originates from D6 (15.1%), D8 (10.2%), D10 (32.9%), and D11 (8.6%), with the remaining drains contributing the rest. These spring-fed drains drain catchments that are intensively farmed by dairy, sheep and beef, dairy grazing and deer. The upper Barkers Creek catchment and the four spring-fed drains are the key DRP hotspots in Barkers Creek, cumulatively contributing 80% of the load exported to the Waihi River. They are the key contributors to DRP load exported via Barkers Creek to the Waihi River. The mass balance suggests that groundwater seepage is not expected to be contributing significantly to DRP loads in Barkers Creek. A breakdown of the relative load comparison is shown spatially in Figure 6-3.

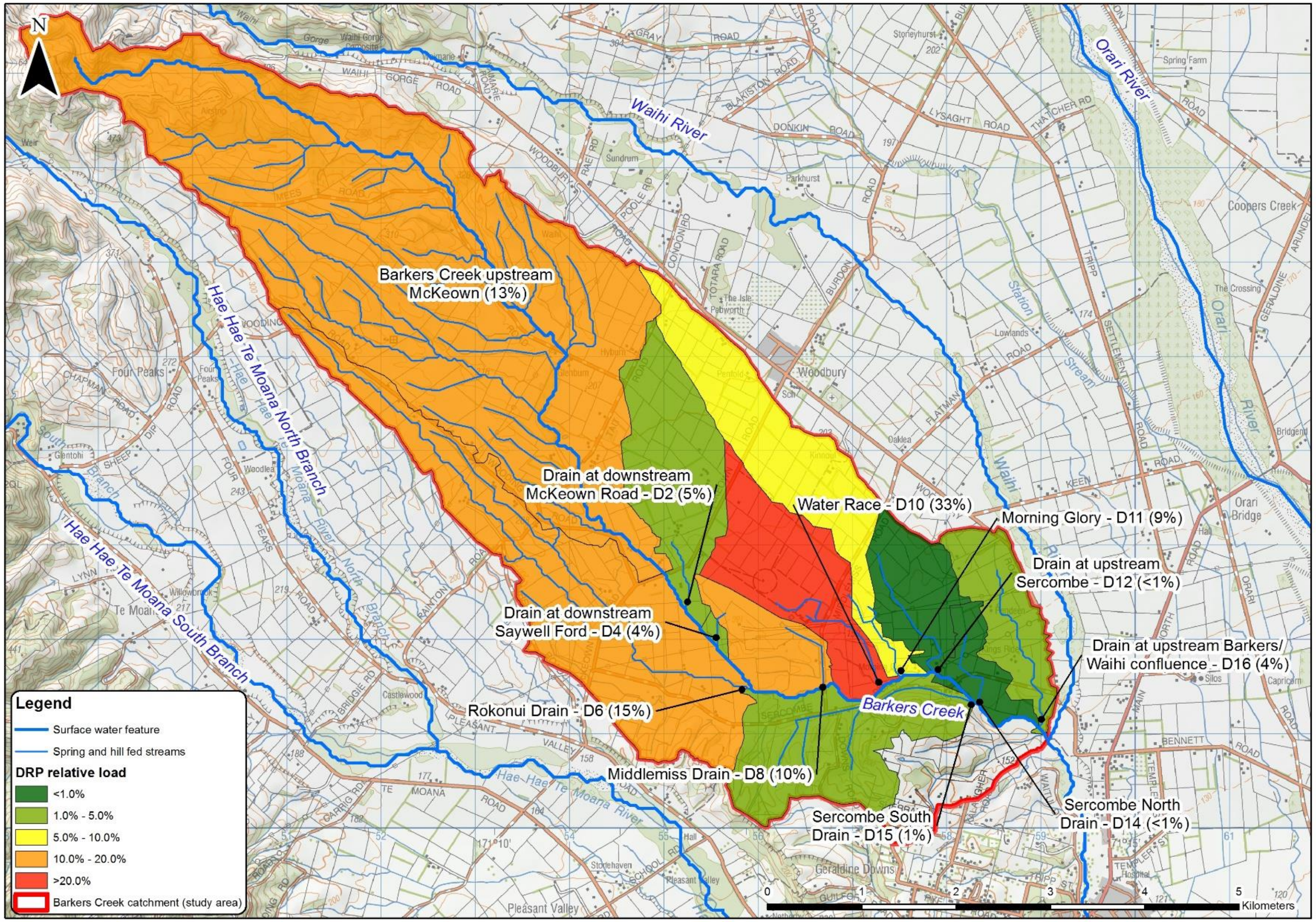

Figure 6-3: Dissolved reactive phosphorus effective source zones in the Barkers Creek catchment

6.3 Temporal dynamics of contaminants of concern

Antecedent catchment conditions are an important factor in understanding the water quality data collected through this study. Rainfall over the fieldwork period (1 September 2016 to 31 August 2017) was 160 mm (18%) above average. March and July 2017 saw the highest recorded monthly rainfall on the 11 year record. The three months prior to sampling starting (June 2016 to August 2016) and September 2016 monthly rainfall was below monthly averages, and the catchment was observed to be in a dry state. From March 2017 to August 2017, conditions within the catchment were very wet, with waterlogged paddocks being a standard occurrence during sampling runs.

Temporal variations in nitrate-nitrogen concentration in groundwater are variable. In the two deeper groundwater monitoring sites (greater than 30 m) nitrate-nitrogen concentrations had little variation in concentrations and were lower across the 12 month monitoring period in the lower Barkers Creek catchment. Concentrations were also lower than what was measured in shallower groundwater. This demonstrates that deep groundwater is buffered from present day LSR, with current concentrations likely reflecting older LSR from less intensive catchment land use. This is consistent with vertical hydraulic gradient in groundwater which indicate upwards migration of deep groundwater across much of the lower Barkers Creek catchment. Alternatively, the low concentrations relative to shallow groundwater reflects the mixed redox state of groundwater at these depths and some denitrification could be occurring.

Unlike the deeper groundwater monitoring sites, shallower groundwater (sampled sites were less than 12 m deep) show temporal variations in nitrate-nitrogen concentrations.

Nitrate-nitrogen concentrations peaked at all three sites during mid-January 2017 and again at the end of May 2017. The pattern in these concentrations reflects the rainfall pattern in the catchment across the monitoring period of this study (September 2016 to August 2017). During periods of 'wetter' climatic conditions nitrate-nitrogen concentrations increased. This was probably due to rainfall recharge flushing nitrate-nitrogen through the vadose zone and into groundwater. Conversely, during periods of 'drier' climatic conditions, nitrate-nitrogen concentrations decreased. This was likely due to minimal rainfall recharge being available to flush the nitrogen through the vadose zone and into groundwater. The overall pattern of nitrate-nitrogen concentrations in groundwater also applies to the majority of spring-fed drains monitored for this study.

This pattern of higher nitrate-nitrogen concentrations during wetter periods and lower during drier periods was also reflected in the main stem of Barkers Creek. This is consistent with the fact that Barkers Creek is fed by groundwater seepage through the stream bed and the spring-fed (groundwater-fed) drains. Like groundwater, nitrate-nitrogen concentrations peaked at all three sites during mid-January 2017 and again at the end of May 2017 during periods of 'wetter' climatic conditions.

Temporal variations in DRP concentration in groundwater are variable. In groundwater, DRP concentrations vary little across the monitoring period in the shallower (less than 12 m bgl) groundwater monitoring sites. This suggests there is little phosphorus making it through the vadose zone to groundwater and is instead adsorbing to the sediment. This is supported by DRP concentrations in shallower groundwater not being significantly higher than what is in the deeper groundwater sampling sites. The phosphorus potentially being held in the sediment suggests that discharge to groundwater and runoff to surface water during rainfall events will be a key pathway for DRP transfer to Barkers Creek. In the two deeper groundwater monitoring sites (greater than 30 m) DRP concentrations were more variable across the 12 month monitoring period. This is likely reflecting a natural source of phosphorus in the aquifer sediments. The similar concentrations in DRP between shallow and deep groundwater in the Barkers Creek catchment suggests the redox state of groundwater is not having a significant impact on DRP concentrations.

The antecedent conditions and magnitudes of the flow event are important for understanding the dynamics of the storm events. As Barkers Creek only had a 1 year flow record, the magnitude of each storm event was established by determining the return period on three other rivers for the same event. The Waihi River, Hae Hae Te Moana River and Temuka River flow records were used.

For Event 1 in March 2017, the catchment was in a dry state with rainfall being below average the preceding three months, and groundwater levels were low. The return period of this event was less than one year[15] (i.e. flow was less than mean annual).

Event 1 with had an average hourly rainfall intensity of 1 mm. Nitrogen concentrations for most species (ammonia-nitrogen was generally below detection levels through Event 1) mirrored the hydrograph at both monitoring sites (although more subdued at Sercombe Road). This was likely more a reflection of the antecedent catchment

[15] Based on flow records for Waihi River, Hae Hae Te Moana River and Temuka River

conditions (i.e. low rainfall and groundwater levels). Under these conditions, nitrogen isn't flushing through the vadose zone or running off the land as frequently as it would under wet conditions. As a result, it builds up and is held in the sediment until a rainfall event flushes it through into surface water and groundwater. This was reflected in the low nitrate-nitrogen concentrations in Barkers Creek prior to the start of the event. As rainfall progressed and flows increased, so too did nitrate-nitrogen concentrations. Daily nitrate-nitrogen loads in this low intensity rainfall event were within the range of daily loads measured across the 26 sampling events undertaken.

These antecedent conditions were a point of difference between the three storm events sampled as the other two events occurred following higher rainfall periods and elevated groundwater levels compared with Event 1. These events had higher rainfall intensities with Event 2 peaking at 4mm/hour and Event 3 peaking at 9.5 mm/hour. While the return period of Event 2 was again less than one year[16] (i.e. flow was less than mean annual flow), Event 3 had a return period of between 5 and 10 years[16]. This antecedent condition was reflected in nitrate-nitrogen concentrations prior to the storm events being higher than during Event 1, reflecting discharge via groundwater seepage and spring-fed drains during the wetter antecedent conditions. During these other event conditions nitrate-nitrogen concentrations were typically following an inverse pattern to the hydrograph. Again, this is likely related to the fact that nitrate-nitrogen concentrations prior to the events were similar to the peak nitrate-nitrogen concentration reach in Event 1. Interestingly, the 2 higher flow events (particularly Event 3) had high concentrations of organic nitrogen being exported from the

[16] Based on flow records for Waihi River, Hae Hae Te Moana River and Temuka River

catchment. Nitrate-nitrogen loads under these events were not significantly higher than what was under baseflow with daily loads being 2 to 5 times the loads under baseflow conditions at Sercombe Road. These higher loads only lasted for a day or two over the event before falling back below the loads under baseflow conditions. This suggests that while loads can be higher during storm flow events, overall loads at baseflow are contributing significantly to the export of nitrate-nitrogen from Barkers Creek into the Waihi River.

The antecedent conditions appear to have little impact on DRP and TSS concentrations and loads. This is because all three storm events that were monitored showed the same DRP and TSS patterns. Instead, the magnitude and intensity of rainfall appear to the driving factor behind DRP and TSS export to Barkers Creek. Based on the three storm sampling events the higher the intensity and amount of rainfall that occurs, the greater the concentrations and loads of DRP and TSS are in Barkers Creek.

Like nitrogen, phosphorus and TSS concentrations and loads varied considerably during each of the three storm events sampled for this study. Again, the intensity and duration of rainfall appears to control the concentrations and loads in Barkers Creek. However, unlike nitrogen, while DRP and TSS concentrations varied across each event, the concentrations did mirror the hydrograph in all cases, generally peaking during peaks in flows. During the high intensity rainfall events (namely Event 2 and Event 3) the DRP daily export is on the order of 1000 times greater than baseflow loads, with TSS being even greater at up to 16750 times. With these comparisons to baseflow, it is clear that DRP and TSS export is very much controlled by rainfall events which activate the overland flow/runoff pathway for the contaminants to reach Barkers Creek.

6.4 Limitations of this study

A key limitation of this study was the frequency at which samples were able to be taken and gaugings able to be made at all groundwater, spring-fed drain and Barkers Creek monitoring sites. The bimonthly occurrences would have been more useful at a higher temporal resolution (e.g. monthly). This higher temporal resolution would have allowed for a more accurate understanding of the relative nitrogen, phosphorus and sediment load contributions of the various sources to Barkers Creek.

While conditions in the catchment appeared to be at average levels (with respect to flow and groundwater levels), the area had been under drought like conditions the preceding two years. This could have impacted the hydrochemistry results and the trends in nutrient concentrations (particularly nitrate-nitrogen).

Much of the hydrochemistry results are based off of one sampling round, undertaken in September 2016. This therefore assumes that those samples are representative of baseline groundwater and surface water chemistry in the Barkers Creek catchment. More frequent sampling of these site for chemistry would have been useful, to better understand catchment chemistry and identify any potential seasonal variations.

Barkers Creek flow and groundwater level record lengths in the catchment were limited to the 12 month period of this study. Validation was attempted by comparing the flows and groundwater levels to out of catchment sites with longer records to help understand the dynamics of the data that was collected. However, this does assume that flows and groundwater levels behave and respond in a similar manner.

For the piezometric survey that was undertaken, there were large data gaps due to the limited groundwater exploration/development that has occurred within the catchment. This was of particular issue inland of McKeown Road and to the south of Barkers Creek.

Groundwater quality monitoring was limited to five sites (one which only had 2 samples collected). A larger spatial distribution of sites at more variable depths would have helped to better understand the nitrogen and phosphorus dynamics in groundwater.

7 Conclusions and scope for future research

7.1 Conclusions

The Barkers Creek catchment functions much like a hydrological basin, flow is governed by geological faults and most notable an anticline running across the lower Barkers Creek catchment. The Geraldine Downs are a basalt extrusion providing a barrier to flow.

Over much of the lower Barkers Creek catchment, the is upwards migration of groundwater from depth. There is also expected to be downwards gradients in the upper catchment, providing a recharge zone to groundwater. Between McKeown Road and the confluence with the Waihi River, Barkers Creek has a series of gaining and losing reaches with an overall net gain from groundwater contributing an average of 44% of total flow.

Hydrochemistry suggests that flow paths/residence time between the recharge and discharge zones for groundwater are short. Barkers Creek has a different chemical signature to the Waihi River and reflects the interaction with older sediments which contain more weathered greywacke and therefore an increasing clay content. Shallow groundwater in the Barkers Creek catchment shows anthropogenic influence with high nitrate-nitrogen concentrations, while deep groundwater reflects a mixed/anoxic redox state and the potential for denitrification to occur. There is evidence of Waihi River recharge into groundwater in the Barkers Creek catchment.

Nitrate-nitrogen and DRP concentrations are typically higher in groundwater and some of the spring-fed drains than what is in Barkers Creek. There appears little temporal variation in nitrate-nitrogen concentrations in deep groundwater, while concentrations in shallow groundwater are driven by climate (higher during wetter periods). This pattern also applies to nitrate-nitrogen concentrations in the spring-fed drains. Groundwater DRP concentrations reflect a natural component, sourced from the sediments and there is little temporal variation.

Groundwater accounts for 20% of total nitrate-nitrogen load exported via Barkers Creek to the Waihi River. A further 11% is from Barkers Creek, upstream of McKeown Road and the remaining 69% is sourced from the spring-fed drains. The hotspots for nitrate-nitrogen load are D4, D10 and D11, contributing 56% of the load exported via Barkers Creek to the Waihi River. DRP load to Barkers Creek from groundwater is minimal, with all of the load exported from Barkers Creek to the Waihi River attributable to the spring-fed drains. Only during flow above baseflow does Barkers Creek gain load from groundwater. 13% of total DRP load exported via Barkers Creek to the Waihi River is from upstream of McKeown Road. With the remainder being sourced from the spring-fed drains. The hotspots for DRP under baseflow conditions are D6, D8, D10 and D11.

Nitrate-nitrogen loads under storm are not significantly higher than what is measured during baseflow conditions. While they can become elevated above baseflow loads, overall loads at baseflow are contributing significantly to the export of nitrate-nitrogen from Barkers Creek into the Waihi River. Phosphorus and TSS concentrations and loads varied considerably during each of the three storm events sampled for this study.

There is a direct relationship between phosphorus and TSS concentrations in the Barkers Creek catchment. Relative loads are considerably higher during storm events compared to baseflow conditions. Annual export of phosphorus and TSS is controlled by flow, with storm events being the major export pathway from Barkers Creek to the Waihi River.

7.2 Scope for future research

The conceptual understanding of the hydrology, hydrogeology, hydrochemistry and nutrient transfer pathways developed in this study can be improved upon with the following research:

1. Little groundwater information was able to be collected inland of McKeown Road. Future installation of bores would aid refining the understanding gained from the piezometric contours and vertical gradients.
2. Development of a history of the land use in the Barkers Creek catchment. This would help refine interpretation of groundwater quality and provide a better understanding of the nutrient sources.
3. Flow gauging of tributaries and the main stem of Barkers Creek upstream of McKeown Road to aid identifying losing reaches and recharge zones to groundwater.
4. Isotope and age dating of groundwater, surface water and spring-fed drains to further constrain their relationships. Further, they will provide refinement in the interpretation of hydrochemistry and nutrients and what they represent.
5. Examination of phosphorus in sediment to better understand what sediments are providing the natural source of phosphorus to the catchment.
6. Sediment and phosphorus results suggest that transport mechanisms are complex. To better understand these, an investigation into the movement of

sediment and phosphorus in Barkers Creek would be beneficial including the identification of potential sinks in the creek bed (i.e. legacy sources).

7. Continuous nitrate-nitrogen monitoring during storm events would help to establish a high resolution understanding of nitrate-nitrogen dynamics during storm events.

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Appendix A: Selected borelogs

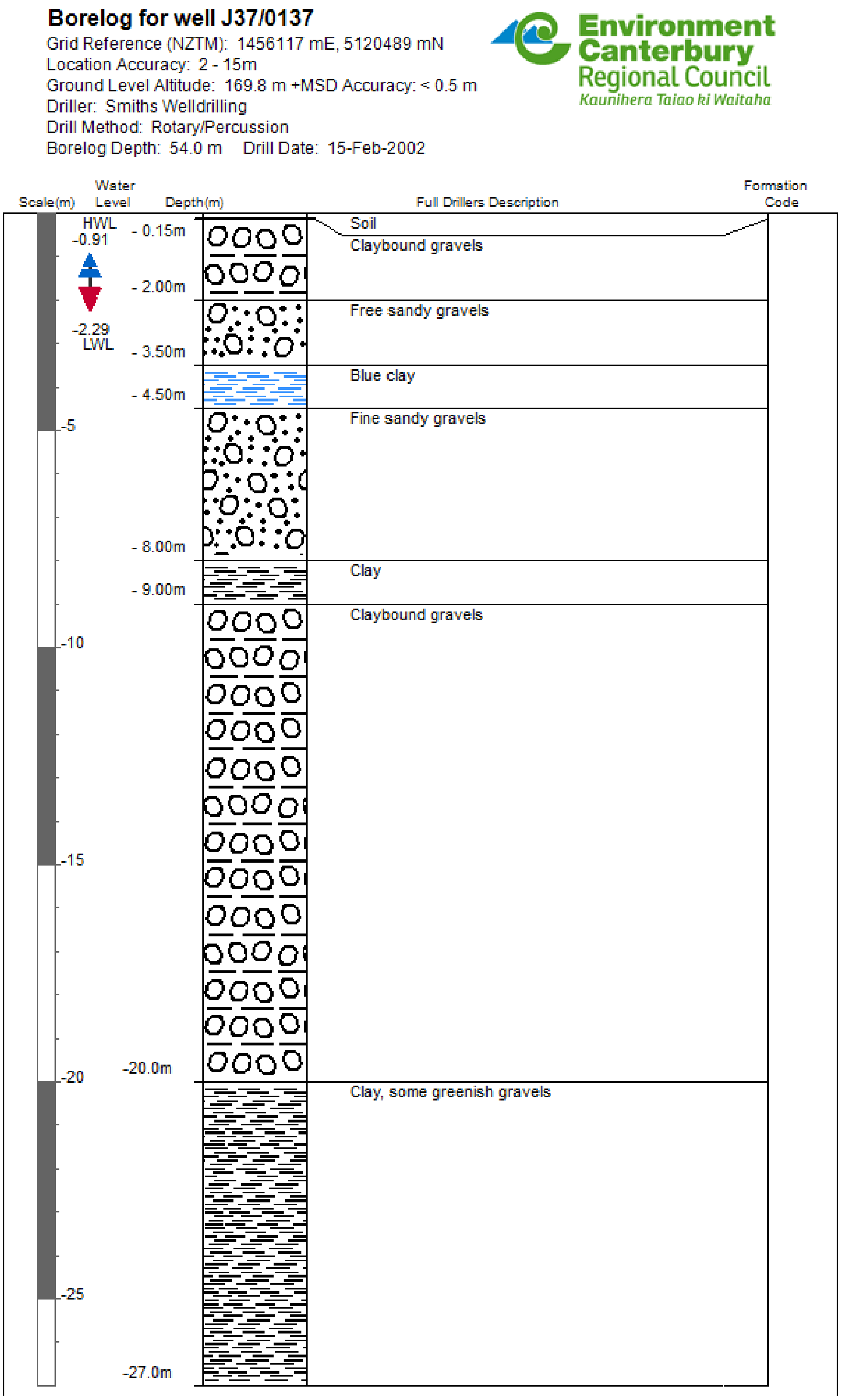

Figure A-1:Borelog for J37/0137 (part 1 of 2)

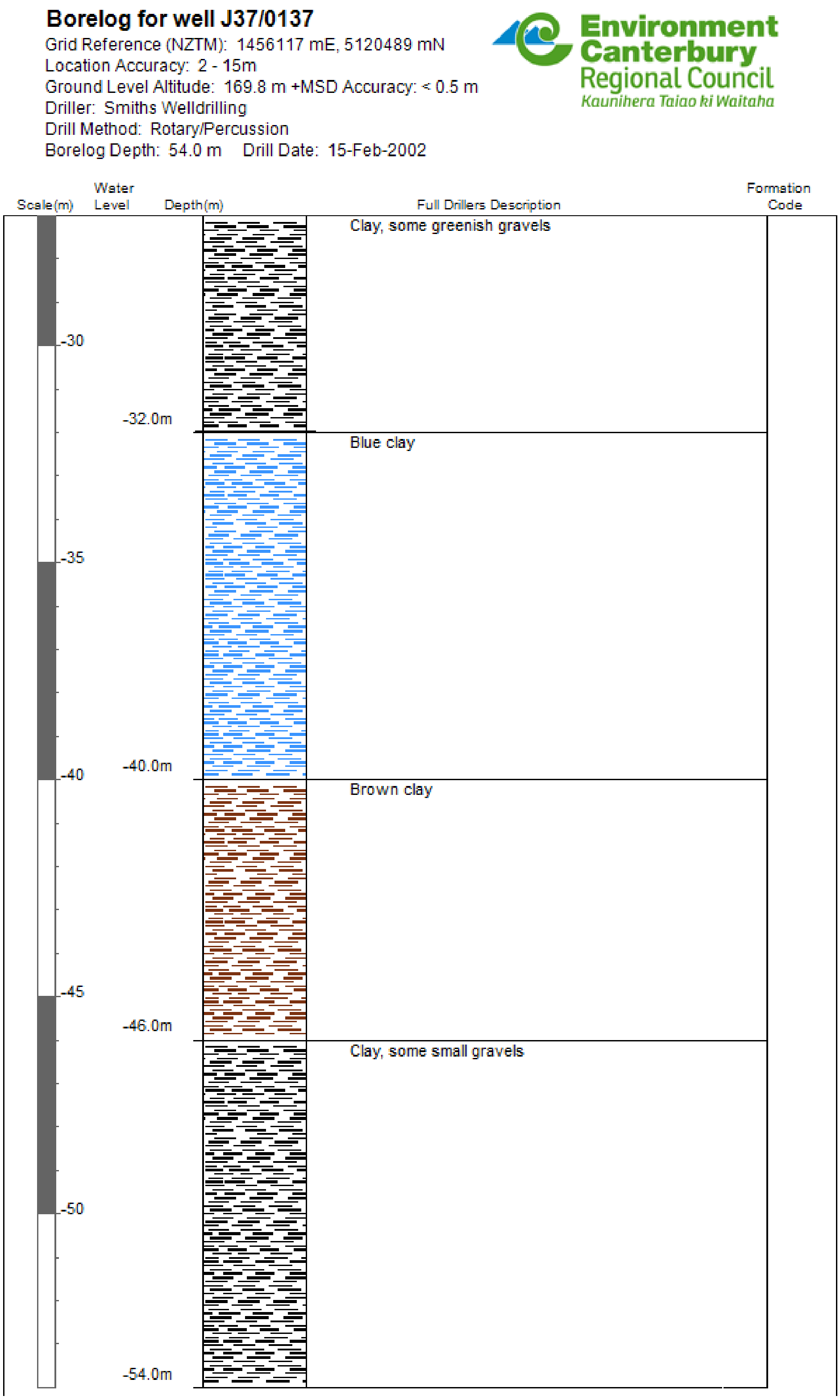

Figure A-2:Borelog for J37/0137 (part 2 of 2)

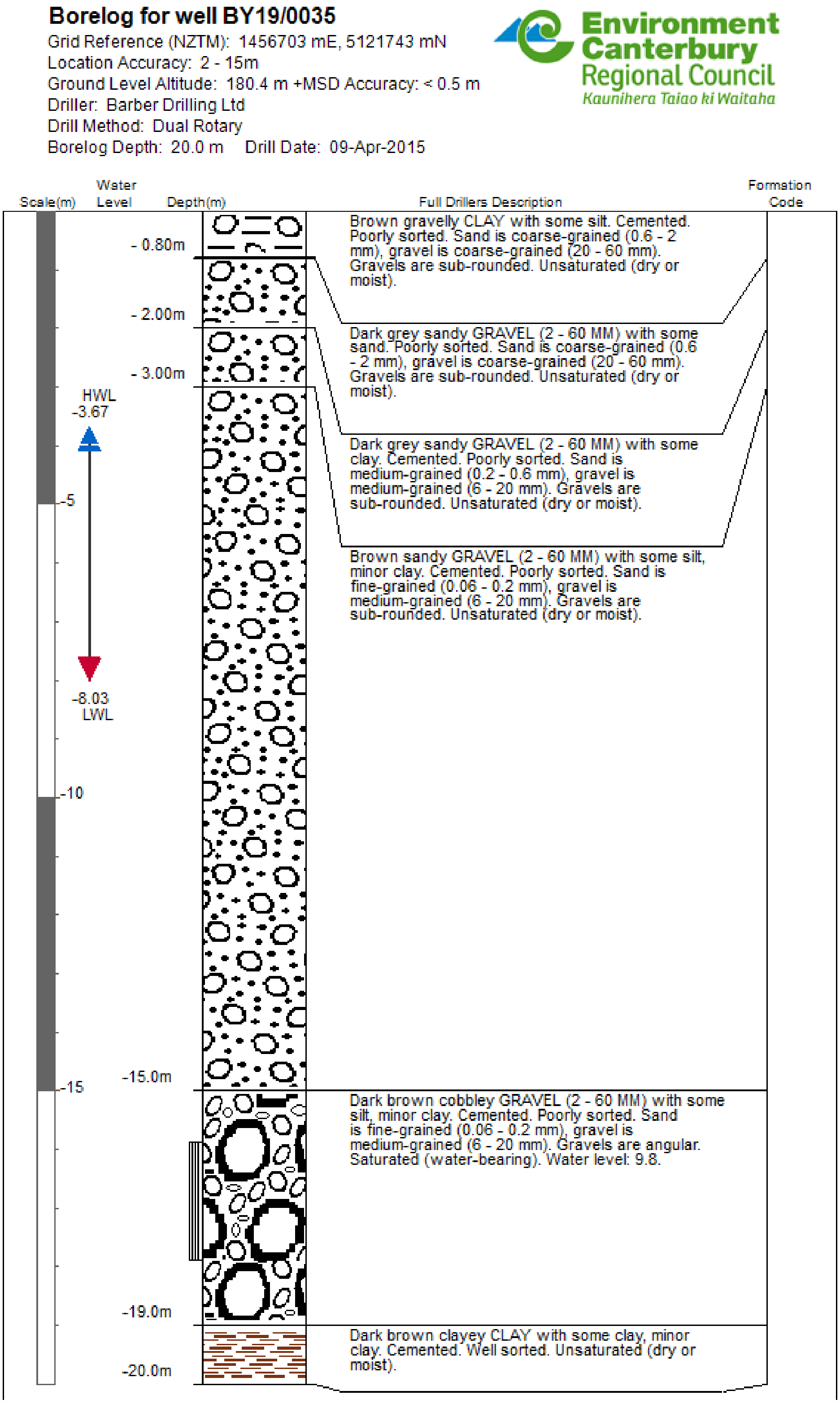

Figure A-3: Borelog for BY19/0035

Appendix B: Water quality parameters

Table B-1: Groundwater quality parameters measured during this study (fortnightly, bimonthly and storm sampling events)

Field measurements	Lab measurements		
Dissolved oxygen	Nitrite-nitrogen	Nitrate-nitrogen	
Conductivity	Total dissolved nitrogen	Total dissolved phosphorus	
Temperature	Total ammoniacal-nitrogen	Dissolved reactive phosphorus	
pH	-	-	-

Table B-2: Surface water quality parameters measured during this study (fortnightly, bimonthly and storm sampling events)

Field measurements	Lab measurements		
Dissolved oxygen	Nitrite-nitrogen	Nitrate-nitrogen	
Conductivity	Total nitrogen	Total phosphorus	
Temperature	Total ammoniacal-nitrogen	Dissolved reactive phosphorus	
pH	Total suspended solids		-

Table B-3: Extra groundwater and surface water quality/chemistry parameters measured during one-off full chemical analytical suite (one-off broadscale sampling)

Lab measurements			
Bicarbonate	Chloride	Dissolved calcium	Dissolved iron
Dissolved manganese	Dissolved potassium	Conductivity	pH
Sulphate	Total alkalinity	Dissolved arsenic	Dissolved magnesium
Dissolved sodium	Reactive silica	Total hardness	-

Table B-4: Laboratory analysis methods

Test	Method description	Detection limit	Sampled during
Turbidity	Analysis using a Hach 2100 Turbidity meter	0.05 NTU	Fortnightly, bimonthly and broadscale survey
Total suspended solids	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5µm), gravimetric determination	3 mg/L	Fortnightly, bimonthly and broadscale survey
Total nitrogen	Alkaline persulphate digestion, automated Cd reduction/sulphanilamide colorimetry	0.01 mg/L	Fortnightly, bimonthly and broadscale survey
Total Ammoniacal-Nitrogen	Filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH_4^- N = NH_4^+ - N + NH_3^- - N)	0.01 mg/L	Fortnightly, bimonthly and broadscale survey
Nitrite-Nitrogen	Filtered sample. Automated Azo dye colorimetry, Flow injection analyser	0.002 mg/L	Fortnightly, bimonthly and broadscale survey
Nitrate-Nitrogen	Calculation: (Nitrate-Nitrogen + Nitrite-Nitrogen) - NO_2N	0.001 mg/L	Fortnightly, bimonthly and broadscale survey
Nitrate-Nitrogen + Nitrite-Nitrogen	Filtered sample. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser	0.002 mg/L	Fortnightly, bimonthly and broadscale survey
Total dissolved nitrogen	Filtered sample. Alkaline persulphate digestion, automated Cd reduction/sulphanilamide colorimetry	0.01 mg/L	Fortnightly, bimonthly and broadscale survey
Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colorimetry. Flow injection analyser	0.001 mg/L	Fortnightly, bimonthly and broadscale survey
Total Dissolved Phosphorus	Filtered sample. Total dissolved phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser	0.004 mg/L	Fortnightly, bimonthly and broadscale survey
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser	0.004 mg/L	Fortnightly, bimonthly and broadscale survey
pH	pH meter	0.1 pH units	Broadscale survey
Total alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator	1.0 mg/L as $CaCO_3$	Broadscale survey
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates	1.0 mg/L at 25°C	Broadscale survey
Total hardness	Calculation from Calcium and Magnesium	1.0 mg/L as $CaCO_3$	Broadscale survey

Test	Method description	Detection limit	Sampled during
Electrical conductivity	Conductivity meter, 25°C	0.1 mS/m	Broadscale survey
Dissolved arsenic	Filtered sample, ICP-MS, trace level	0.001 mg/L	Broadscale survey
Dissolved calcium	Filtered sample, ICP-MS, trace level	0.05 mg/L	Broadscale survey
Dissolved iron	Filtered sample, ICP-MS, trace level	0.02 mg/L	Broadscale survey
Dissolved magnesium	Filtered sample, ICP-MS, trace level	0.02 mg/L	Broadscale survey
Dissolved manganese	Filtered sample, ICP-MS, trace level	0.0005 mg/L	Broadscale survey
Dissolved potassium	Filtered sample, ICP-MS, trace level	0.05 mg/L	Broadscale survey
Dissolved sodium	Filtered sample, ICP-MS, trace level	0.02 mg/L	Broadscale survey
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser	0.5 mg/L	Broadscale survey
Reactive silica	Filtered sample. Heteropoly blue colorimetry. Discrete analyser	0.1 mg/L as SiO_2	Broadscale survey
Sulphate	Filtered sample. Ion Chromatography	0.5 mg/L	Broadscale survey
Total anions for anion/cation balance check	Calculation: sum of anions as mEquiv/L		Broadscale survey
Total cations for anion/cation balance check	Sum of cations as mEquiv/L		Broadscale survey
% Difference in Ion Balance	Calculation from Sum of Anions and Cations		Broadscale survey

Appendix C: Rating curves

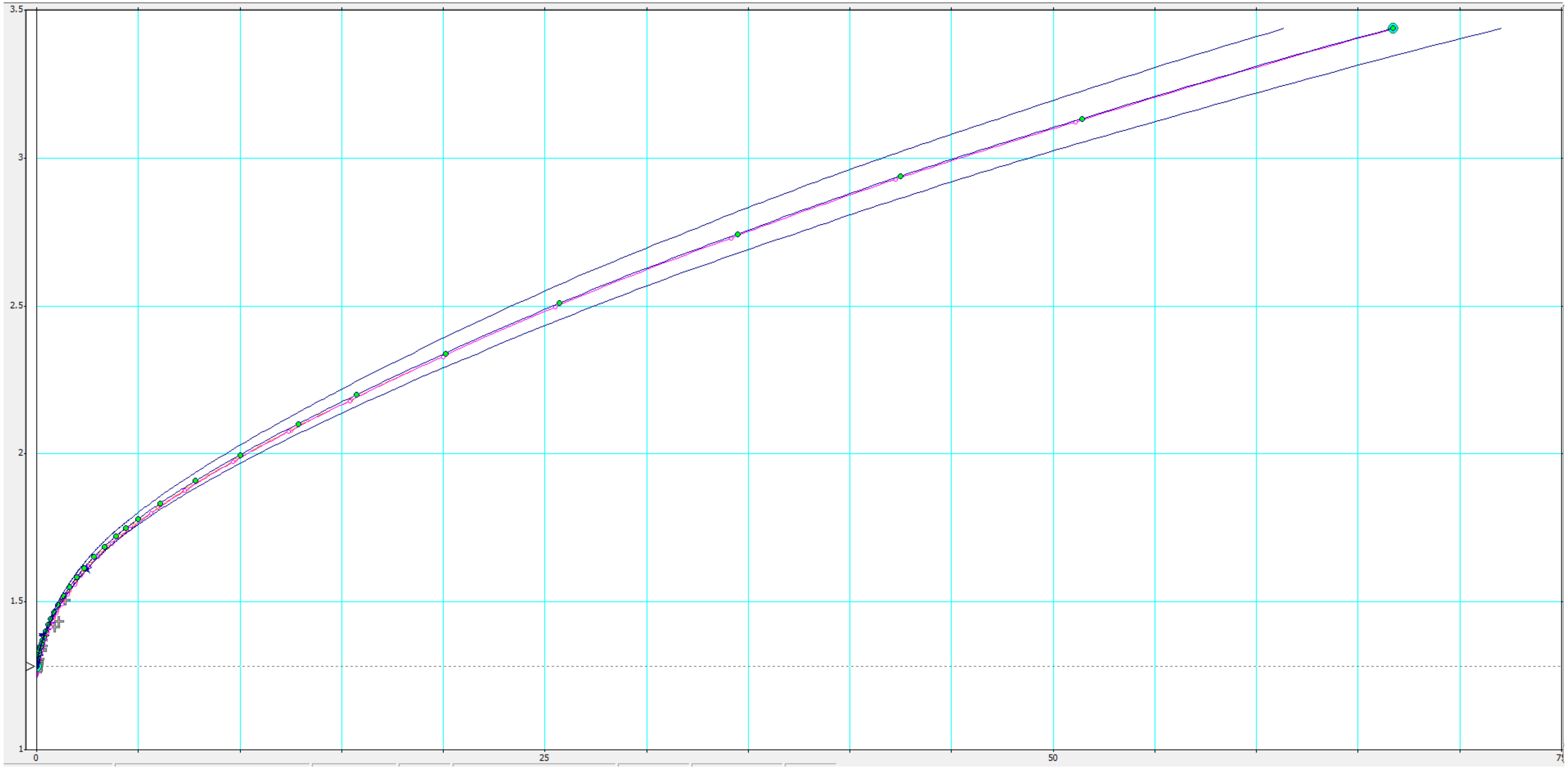

Figure C-1:Rating curves for Barkers Creek at McKeown Road for data period 1 September 2016 to 31 August 2017

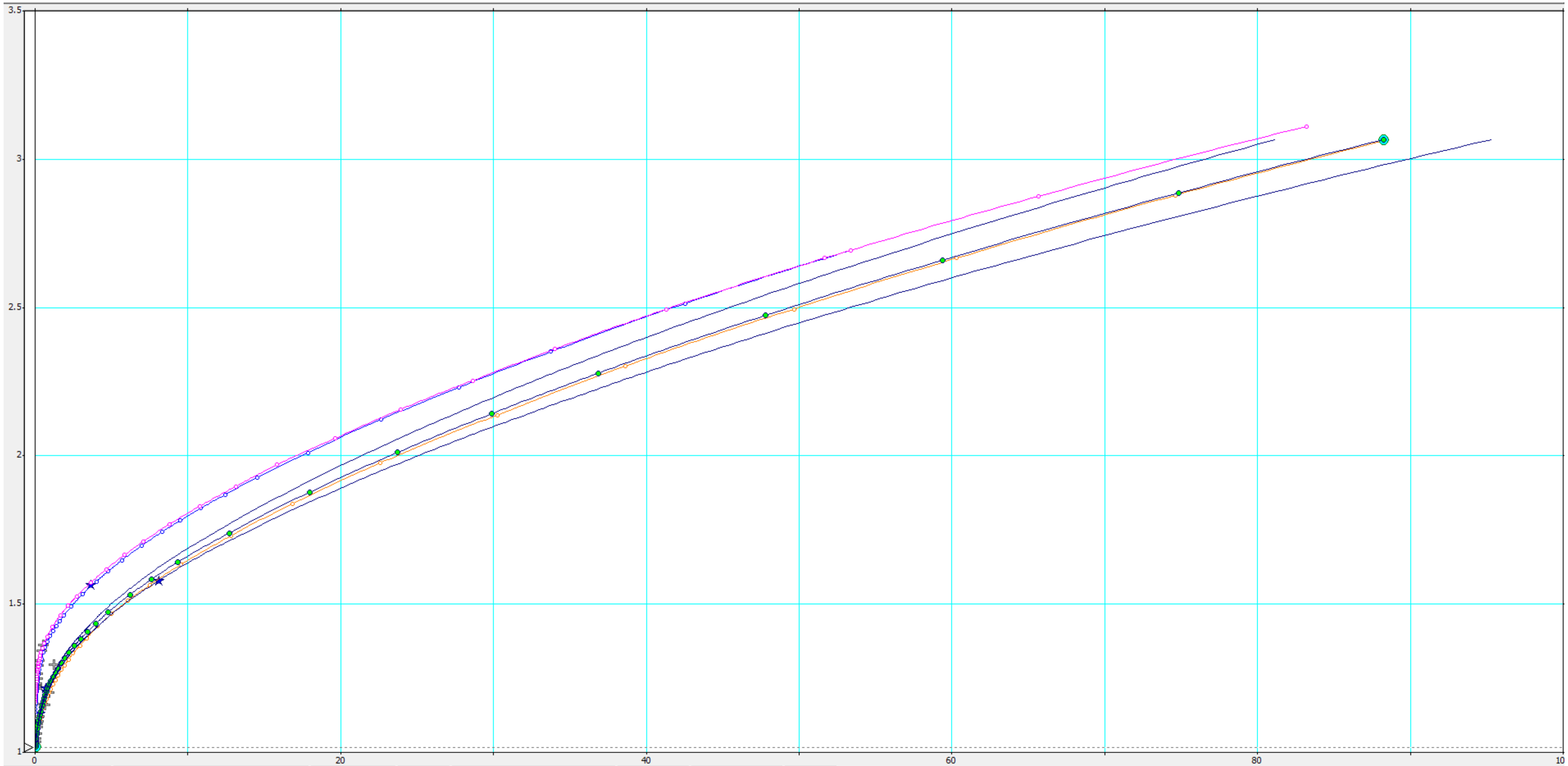

Figure C-2:Rating curves for Barkers Creek at Sercombe Road for data period 1 September 2016 to 31 August 2017

Appendix D: Piezometric survey data

Table D-1: Piezometric survey data

Bore number	Easting	Northing	Ground level (m msl)	Bore depth (m bgl)	Measuring point (m fgl)	Screen (m bgl)	Screen middle (m bgl)	Bore bottom elevation (m msl)	Representative screen level (m msl)	Depth to water (m bmp)	Depth to water (m bgl)	Water level (m msl)
BY19/0013	1451883	5123156	251.79	54	-0.34	37 - 52	49.5	197.79	202.29	-28.75	-28.41	223.38
BY19/0035	1456703	5121743	180.427	17.88	-0.52	15.88 - 17.88	16.88	162.547	163.547	-7.63	-7.11	173.317
BY19/0071	1456521	5123001	197.23	18	-0.59	15.33 - 17.33	16.33	179.23	180.9	-9.09	-8.5	188.73
BY19/0091	1456792	5121796	180.173	6.7	0	-	5.2	173.473	174.973	-3.09	-3.09	177.083
J37/0001	1456584	5123100	197.335	15.25	-0.2	-	13.75	182.085	183.585	-6.34	-6.14	191.195
J37/0009	1458935	5123056	173.54	11.2	-0.6	-	9.7	162.34	163.84	-6.31	-5.71	167.83
J37/0029	1459910	5118819	131.97	7.5	-0.09	2.5 - 7.5	5	124.47	126.97	-1.37	-1.28	130.69
J37/0038	1455301	5120803	177.083	10	-0.11	-	8.5	167.083	168.583	-2.8	-2.69	174.393
J37/0042	1456454	5122888	196.642	11.5	-0.32	7.5 - 11.5	9.5	185.142	187.142	-8.06	-7.74	188.902
J37/0045	1456148	5122813	198.55	13	-0.37	-	11.5	185.55	187.05	-7.91	-7.54	191.01
J37/0050	1455341	5124908	229.028	5	-0.33	0.3 - 5	2.65	224.028	226.378	-2.115	-1.785	227.243
J37/0053	1457509	5125295	196.68	10.65	-0.13	-	9.15	186.03	187.53	-4.85	-4.72	191.96

J37/0055	1459072	5120189	148.043	9.5	-0.2	4 - 9	6.5	138.543	141.543	-3.25	-3.05	144.993
J37/0092	1455178	5120620	175.28	5.6	0	-	4.1	169.68	171.18	-2.14	-2.14	173.14
J37/0108	1457279	5120902	165.693	1.6	-0.35	-	1.6	164.093	164.093	-0.69	-0.34	165.353
J37/0116	1456408	5120393	166.506	1.29	-0.23	-	1.29	165.216	165.216	-0.5	-0.27	166.236
J37/0137	1456117	5120489	169.83	54	-0.53	-	54	115.83	115.83	-2.82	-2.29	167.54
J37/0185	1455382	5121799	189.67	35.2	-0.76	17 - 25	21	154.47	168.67	-9.34	-8.58	181.09
J37/0189	1458035	5121459	166.974	9	-0.2	3 - 9	6	157.974	160.974	-3.03	-2.83	164.144
J37/0197	1457083	5123714	197.034	8.5	-0.32	6 - 8.5	7.25	188.534	189.784	-5.36	-5.04	191.994
J37/0202	1458382	5120346	156.628	62.66	-0.38	58.66 - 62.66	60.66	93.968	95.968	-12.08	-11.7	144.928
J37/0216	1457009	5123527	196.252	84	-0.585	16 - 25, 40 - 54, 70 - 78		112.252	196.252	-9.82	-9.235	187.017
J37/0257	1456581	5120223	163.784	2.94	-0.18	-	2.94	160.844	160.844	-0.63	-0.45	163.334
J37/0284	1451906	5123152	251.08	37	-0.36	35 - 37	36	214.08	215.08	-35.27	-34.91	216.17
J37/0297	1455586	5121388	182.73	12	-0.38	-	10.5	170.73	172.23	-7.83	-7.45	175.28
J37/0298	1455662	5121587	184.99	13.5	-0.34	8 - 13.5	10.75	171.49	174.24	-7.74	-7.4	177.59
J37/0302	1456246	5122993	199.76	13.8	-0.37	8 - 12.8	10.4	185.96	189.36	-7.88	-7.51	192.25
J37/0325	1454091	5119321	173.352	10	-0.25	-	8.5	163.352	164.852	-1.83	-1.58	171.772
K37/0671	1460827	5121480	152.74	7.6	-0.2	-	6.1	145.14	146.64	-3.46	-3.26	149.48
K37/1301	1460177	5120029	141.81	46	-0.65	43 - 46	44.5	95.81	97.31	-4.09	-3.44	138.37
K37/2923	1461189	5120271	140.17	8.6	-0.46	6.6 - 8.6	7.6	131.57	132.57	-1.575	-1.115	139.055

Appendix E: BY19/0035 correlation

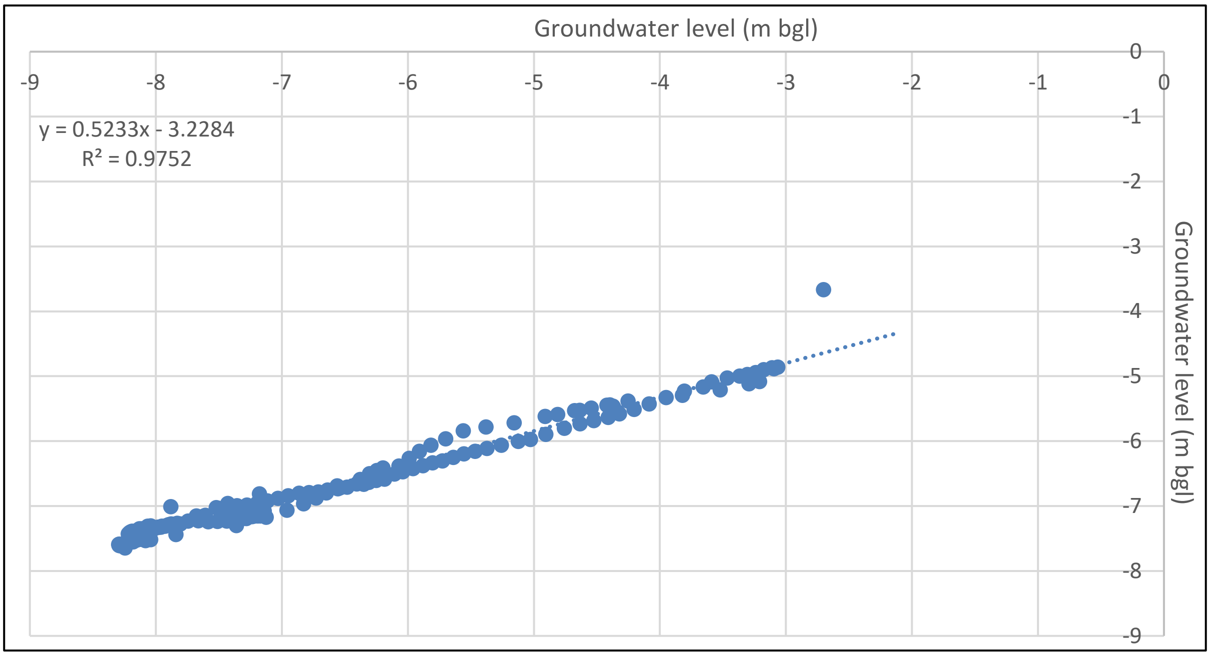

Figure E-1: Groundwater level correlation between BY19/0035 and J37/0297 for data collected between September 2016 and August 2017

Appendix F: Full extent surface water hydrographs

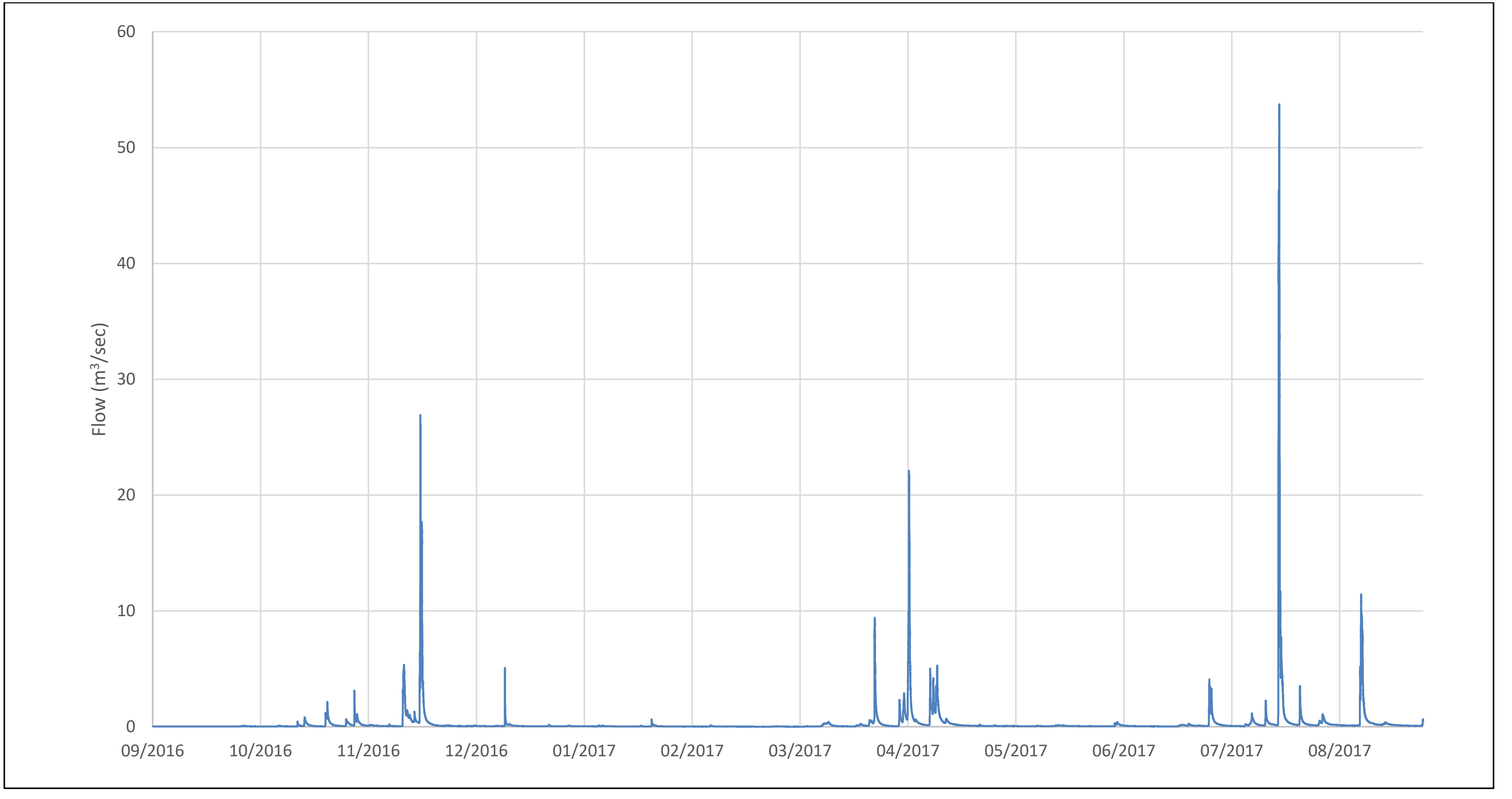

Figure F-1: Surface water flow hydrograph for McKeown Road, Barkers Creek recorder site

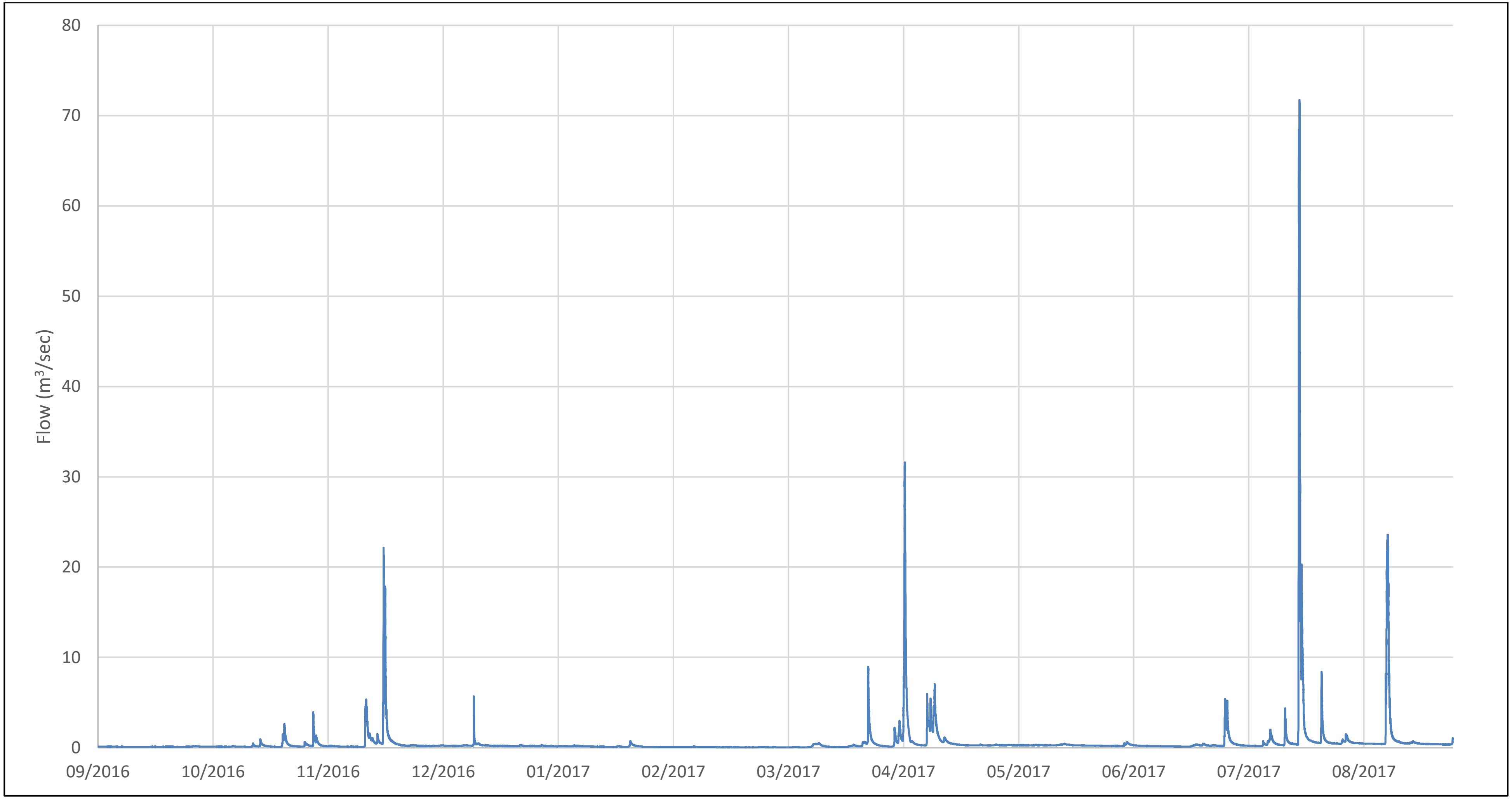

Figure F-2: Surface water flow hydrograph for Sercombe Road, Barkers Creek recorder site

Appendix G: Broadscale survey water chemistry raw data

Table G-1: Broadscale water chemistry data (all data in mg/L)

Site number	Date	NZTMX	NZTMY	Depth	As (mg/L)	Fe (mg/L)	Ca	Cl	Mg	Mn	K	Si	Na	SO_4	NH_3-N	NO_2-N	NO_3-N	Total N	Total Dissolved N	DRP	Total P	Total Dissolved P	Alkalinity as CaCO3	Alkalinity as HCO3	Total Hardness as CaCO3	Conductivity	pH	TSS	pH	DO
SQ36210 (BC0)	1-Sep-16	1453967	5123040	-	< 0.001	0.18	10.6	7.1	2.7	0.0161	1.18	7.1	8.1	11.4	< 0.01	< 0.002	0.007	0.26	-	0.0035	0.015	-	34	42	37	11.7	7.6	<3	6.39	11.2
SQ35957 (BC1)	1-Sep-16	1455030	5120700	-	< 0.001	0.06	10.8	9.7	3	0.0013	1.44	5	8.9	13.6	< 0.01	< 0.002	0.108	0.37	-	< 0.0010	0.009	-	31	38	39	12.8	7.6	<3	6.57	12.3
SQ36211 (D2)	1-Sep-16	1455240	5120359	-	< 0.001	0.02	13.7	13.2	4.8	0.0024	1.36	13.6	12.2	12.1	0.017	0.015	4.8	5	-	0.0112	0.031	-	34	41	54	17.8	7.4	6	6.37	10.31
SQ36212 (BC3)	1-Sep-16	1455507	5120025	-	< 0.001	0.03	11.4	10.1	3.3	0.0007	1.42	6.4	9.6	13.5	< 0.01	0.003	0.84	1.07	-	< 0.0010	0.01	-	32	39	42	13.8	7.6	<3	6.98	12.9
SQ36213 (D4)	1-Sep-16	1455569	5119963	-	< 0.001	< 0.02	14.3	12.3	5.4	0.0029	1.25	16.8	11.7	13.4	< 0.01	< 0.002	5.6	5.7	-	0.0169	0.034	-	34	41	58	18.7	7.3	5	6.67	10.5
SQ36214 (BC5)	1-Sep-16	1455908	5119495	-	< 0.001	0.04	11.4	10.4	3.5	0.0012	1.42	6.8	9.9	13.7	< 0.01	0.005	1.03	1.31	-	< 0.0010	0.011	-	33	40	43	14.2	7.7	<3	7.81	14.11
SQ36215 (D6)	1-Sep-16	1455888	5119485	-	< 0.001	0.62	18.2	24	7.3	0.039	3.6	13.6	18.8	18.4	0.27	0.025	0.72	1.85	-	0.034	0.22	-	66	81	76	25.2	7.7	33	7.46	10.59
SQ36216 (BC7)	1-Sep-16	1456658	5119495	-	< 0.001	0.08	11.7	11.9	3.8	0.0008	1.68	6.8	11	14.3	< 0.01	0.008	0.85	1.18	-	0.0056	0.023	-	38	46	45	14.9	7.9	4	8.21	16.58
SQ36217 (D8)	1-Sep-16	1456658	5119555	-	< 0.001	0.03	15.2	15.2	6.1	0.0023	1.36	12.1	12.6	11.7	< 0.01	0.003	2.9	3	-	0.027	0.039	-	48	59	63	19.3	7.7	<3	7.77	11.77
SQ36218 (BC9)	1-Sep-16	1457297	5119525	-	< 0.001	0.06	12.5	12.8	4.1	0.001	1.67	6.2	11.3	13.9	< 0.01	0.005	0.99	1.31	-	0.0031	0.02	-	37	45	48	15.7	7.8	4	6.37	13.5
SQ36219 (D10)	1-Sep-16	1457296	5119523	-	< 0.001	< 0.02	14.7	12.8	5.4	0.0016	1.34	15.3	11.7	8.3	< 0.01	0.003	5.5	5.5	-	0.0148	0.027	-	42	51	59	18.7	7.7	6	7.12	10.67
SQ36220 (D11)	1-Sep-16	1457497	5119635	-	< 0.001	< 0.02	11.2	8.8	4.7	0.0012	0.82	15.1	10.6	6.7	0.011	0.009	2.8	2.8	-	0.024	0.032	-	40	49	47	15	7.7	<3	7.2	10.89
SQ36221 (D12)	1-Sep-16	1457827	5119665	-	< 0.001	0.04	10.5	8.6	4.7	0.0023	0.38	15.7	11.2	5.8	0.011	0.004	2.2	2.4	-	0.0027	0.027	-	43	53	46	14.6	7.5	17	6.93	10.58
SQ35956 (BC13)	1-Sep-16	1458110	5119560	-	< 0.001	0.03	12.3	11.5	4.5	< 0.0005	1.4	9.6	11	10.7	< 0.01	0.006	2.3	2.4	-	0.0056	0.022	-	38	46	49	15.9	7.8	4	7.33	14.05
SQ36222 (D14)	1-Sep-16	1458317	5119326	-	< 0.001	< 0.02	13.8	15.9	5.4	< 0.0005	1.48	2.9	12.7	14.5	< 0.01	0.006	1.9	2.1	-	0.0037	0.015	-	38	46	57	18.2	7.7	<3	7.35	13.35
SQ36223 (D15)	1-Sep-16	1458266	5119325	-	< 0.001	0.12	14.3	22	5.8	0.0097	1.97	6.2	17.9	10.6	< 0.01	< 0.002	0.051	0.75	-	0.0064	0.024	-	58	71	60	20.6	7.6	6	6.89	14.29
SQ36224 (D16)	1-Sep-16	1458949	5119147	-	< 0.001	0.02	9.1	8.8	4.1	0.0018	1.29	12.2	11	5.5	0.01	0.005	1.11	1.41	-	0.017	0.029	-	39	48	40	13.1	7.6	7	6.75	11.9
SQ35953 (BC17)	1-Sep-16	1459110	5119040	-	< 0.001	0.03	12.4	12.7	4.5	0.0008	1.52	9.3	11.6	10.4	< 0.01	0.007	2.1	2.5	-	0.0058	0.016	-	38	46	50	16	8	4	8.47	14.7
SQ35955 (W18)	1-Sep-16	1459080	5119020	-	< 0.001	< 0.02	7.8	3.9	2.2	< 0.0005	0.54	12.3	5.1	2.8	< 0.01	< 0.002	0.85	0.94	-	0.0016	0.005	-	27	33	29	8.4	7.5	<3	7.87	12.53
SQ20332	1-Sep-16	1452911	5126107	-	< 0.001	< 0.02	7.3	2.3	2	< 0.0005	0.36	10.3	4.1	1.5	< 0.01	< 0.002	0.145	0.2	-	0.0025	0.007	-	30	36	27	7	7.7	<3	6.38	12.81
BY19/0013	26-Aug-16	1451883	5123156	52	< 0.001	2.1	11.1	7.7	7	0.033	0.72	37	17	3.8	< 0.01	0.006	0.008	-	0.012	0.0105	-	0.01	57	79	97	18.3	7.3	-	-	-
BY19/0035	24-Aug-16	1456703	5121743	18	< 0.001	0.18	12	5.3	5	0.048	0.73	24	10.7	1.9	0.029	0.006	2.6	-	2.7	0.005	-	0.019	50	57	69	15.3	7.4	-	6.44	2.72
J37/0038	23-Aug-16	1455301	5120803	10	< 0.001	< 0.02	13.3	10	4.5	< 0.0005	1.23	19.2	10.7	9.5	< 0.01	< 0.002	6.5	-	6.2	0.0123	-	0.013	52	28	34	16.6	6.6	-	5.57	7.62
J37/0042	23-Aug-16	1456454	5122888	11.5	< 0.001	< 0.02	10.3	6.3	3.9	< 0.0005	0.89	21	10.4	4.1	0.011	< 0.002	4.3	-	4.4	0.0166	-	0.019	42	36	43	13.4	6.7	-	5.66	4.44
J37/0045	24-Aug-16	1456148	5122813	13	< 0.001	0.04	10.4	5.6	2.9	0.0012	1.13	17.7	7.2	7.9	< 0.01	< 0.002	3.9	-	3.9	0.0069	-	0.006	38	27	33	12.6	6.6	-	5.57	8.56
J37/0050	25-Aug-16	1455341	5124908	5	< 0.001	< 0.02	7.5	3.1	1.87	< 0.0005	0.37	11.5	4.1	2.2	< 0.01	0.006	1.02	-	1.05	< 0.0010	-	< 0.004	26	26	32	7.5	7	-	5.95	9.6
J37/0055	24-Aug-16	1459072	5120189	9	< 0.001	< 0.02	9.5	6	3	< 0.0005	0.73	15.8	6.7	4.9	0.032	< 0.002	2.5	-	2.7	0.006	-	0.005	36	29	35	11.3	6.7	-	5.64	8.88
J37/0092	23-Aug-16	1455178	5120620	5.6	< 0.001	< 0.02	12.8	12.7	5.4	< 0.0005	1.08	22	13.4	13.6	< 0.01	< 0.002	4.6	-	4.6	0.0137	-	0.015	54	36	44	18.1	6.7	-	5.59	9.04
J37/0108	26-Aug-16	1457279	5120902	1.6	< 0.001	0.28	14.5	13.7	5.3	0.076	2.1	18.5	11.6	7.6	0.126	0.006	8.4	-	7.6	0.03	-	0.155	58	34	41	18.7	6.5	-	5.6	7.56
J37/0185	25-Aug-16	1455382	5121799	25	< 0.001	< 0.02	11.6	6.4	5.2	< 0.0005	0.55	26	11.1	1.7	< 0.01	< 0.002	2.7	-	2.7	0.0186	-	0.017	51	55	67	15.3	7.4	-	6.35	3.92
J37/0189	26-Aug-16	1458035	5121459	9	< 0.001	< 0.02	10.6	7.1	3.7	< 0.0005	1.04	20	9.6	6.4	< 0.01	< 0.002	4.7	-	4.7	0.0102	-	0.011	42	32	39	13.8	6.8	-	5.58	9.49
J37/0197	23-Aug-16	1457083	5123714	8.5	< 0.001	< 0.02	9.6	4.7	2.7	< 0.0005	0.91	17.8	7.1	4.9	0.027	< 0.002	3.1	-	3.2	0.0088	-	0.008	35	30	37	11.1	6.6	-	5.47	9.13
J37/0202	24-Aug-16	1458382	5120346	63	< 0.001	0.27	14.5	9.2	8.4	0.101	0.75	27	17.3	1.8	0.011	< 0.002	0.004	-	0.017	0.0119	-	0.019	71	97	118	21.3	7.7	-	7.04	1.01
J37/0216	23-Aug-16	1457009	5123527	78	0.0019	0.03	7.3	2.5	2.5	0.0022	0.48	19.3	8.5	1.8	0.013	< 0.002	0.56	-	0.61	0.028	-	0.034	29	41	50	9.3	7.3	-	6.18	4.03

Site number	Date	NZTMX	NZTMY	Depth	As (mg/L)	Fe (mg/L)	Ca	Cl	Mg	Mn	K	Si	Na	SO_4	NH_3-N	NO_2-N	NO_3-N	Total N	Total Dissolved N	DRP	Total P	Total Dissolved P	Alkalinity as CaCO3	Alkalinity as HCO3	Total Hardness as CaCO3	Conductivity	pH	TSS	pH	DO
J37/0297	24-Aug-16	1455586	5121388	12	< 0.001	< 0.02	11.2	6.8	3.9	< 0.0005	1.04	21	9	6.8	< 0.01	< 0.002	4.5	-	4.5	0.0106	-	0.01	44	35	42	14.3	6.7	-	5.73	6.93
J37/0325	25-Aug-16	1454091	5119321	10	< 0.001	< 0.02	11.7	14.8	6.2	< 0.0005	0.43	40	19.1	2.4	< 0.01	< 0.002	2.3	-	2.4	0.028	-	0.028	55	66	81	20.1	7.1	-	6.05	6.11
SQ36225	24-Aug-16	1455686	5120870	0	< 0.001	< 0.02	11.4	9.5	4.1	0.0057	1.26	17.7	10.9	7	< 0.01	0.008	3.7	-	3.9	0.0012	-	0.011	46	37	45	15.1	6.9	-	6.12	12
SQ36226	23-Aug-16	1456216	5120372	0	< 0.001	< 0.02	15.6	15.4	6	0.0007	1.09	20	12.6	8.5	< 0.01	< 0.002	7.3	-	6.8	0.0134	-	0.014	64	38	47	20.5	6.6	-	5.61	5.48
SQ36227	25-Aug-16	1456230	5120163	0	< 0.001	< 0.02	14.7	14.3	5.7	0.003	1.01	21	12.2	10.1	< 0.01	< 0.002	5.9	-	5.7	0.0151	-	0.015	60	40	49	19.4	6.7	-	5.66	7.41
SQ36228	26-Aug-16	1457278	5120901	0	< 0.001	< 0.02	14.3	13.4	5.5	0.0124	1.76	18.7	11.2	7.8	0.033	0.003	8.5	-	7.7	0.079	-	0.079	58	29	35	18.6	6.7	-	5.72	6.58

Appendix H: Water quality cluster box plots

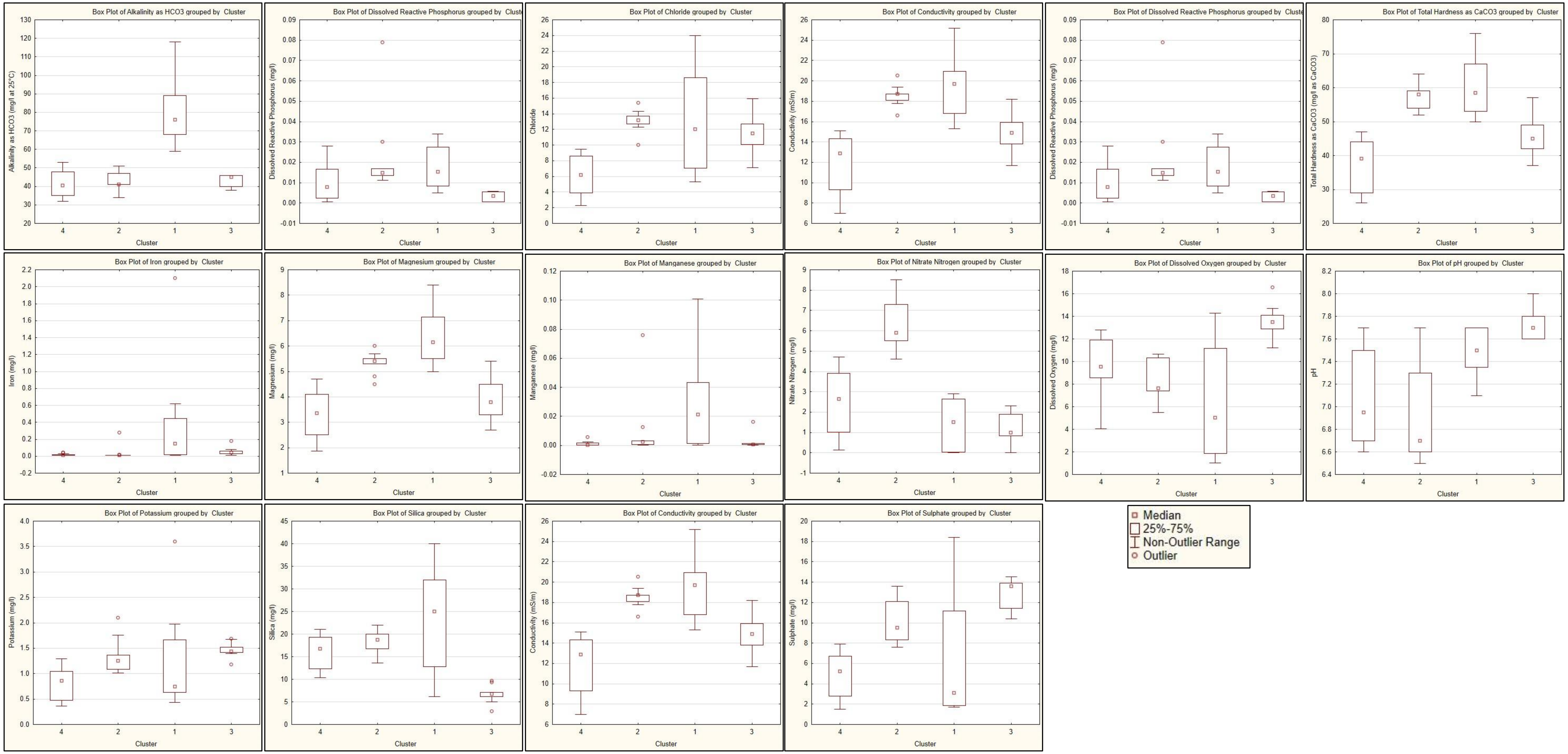

Figure H-1:Box and whisker plots for each parameter showing the range of concentrations observed in bores in each cluster (A1 to B3 along the x-axis). Cluster 1 = A1, cluster 2 = B1, cluster 3 = B2 and cluster 4 = B3

Appendix I: Nutrients and sediment raw data (fortnightly and bimonthly)

Table I-1: Fortnightly and bimonthly nutrient and sediment concentration raw data

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
BC0	SQ36210	1-Sep-16	945	1453967	5123040	< 0.010	< 0.002	0.007	0.26	-	0.0035	0.015		< 3	2.2
	SQ36210	9-Nov-16	840	1453967	5123040	0.021	0.006	0.049	0.57	-	0.0134	0.039		7	6.2
	SQ36210	17-Jan-17	815	1453967	5123040	< 0.010	0.007	0.036	0.49	-	0.0107	0.042		7	6.7
	SQ36210	21-Mar-17	1045	1453967	5123040	< 0.010	< 0.002	0.014	0.36	-	0.0119	0.034		<3	2.3
	SQ36210	30-May-17	955	1453967	5123040	< 0.010	< 0.002	0.013	0.25	-	0.0057	0.041		8	13.7
	SQ36210	19-Jul-17	1230	1453967	5123040	< 0.010	0.003	0.56	0.82	-	0.0068	0.029		<5	7.1
BC1	SQ35957	1-Sep-16	1010	1455030	5120700	< 0.010	< 0.002	0.108	0.37	-	0.0005	0.009		< 3	0.8
	SQ35957	24-Sep-16	1100	1455030	5120700	< 0.010	< 0.002	0.28	0.52	-	0.0005	0.012		< 3	0.63
	SQ35957	15-Oct-16	1130	1455030	5120700	0.044	0.007	0.71	1.44	-	0.0079	0.057		4	9.3
	SQ35957	30-Oct-16	1205	1455030	5120700	< 0.010	0.011	1.18	2.1	-	0.0188	0.058		3	6.6
	SQ35957	9-Nov-16	855	1455030	5120700	< 0.010	0.003	0.04	0.5	-	0.0106	0.029		< 3	1.92
	SQ35957	27-Nov-16	1105	1455030	5120700	< 0.010	0.008	1.21	1.66	-	0.0102	0.029		< 3	1.35
	SQ35957	10-Dec-16	1200	1455030	5120700	< 0.010	0.005	1.35	1.83	-	0.0044	0.021		3	1.8
	SQ35957	21-Dec-16	1235	1455030	5120700	< 0.010	0.006	1.48	1.68	-	0.0047	0.012		< 3	1.03
	SQ35957	6-Jan-17	1040	1455030	5120700	< 0.010	0.003	1.1	1.3	-	0.0026	0.012		< 3	0.86
	SQ35957	17-Jan-17	1410	1455030	5120700	< 0.010	0.003	1.01	1.34	-	0.0027	0.016		< 3	0.85
	SQ35957	2-Feb-17	1310	1455030	5120700	< 0.010	0.003	0.28	0.62	-	0.0032	0.024		< 3	0.76
	SQ35957	16-Feb-17	1040	1455030	5120700	< 0.010	<0.002	0.164	0.47	-	0.0016	0.009		< 3	0.59
	SQ35957	2-Mar-17	1035	1455030	5120700	< 0.010	0.003	0.117	0.31	-	0.0041	0.027		< 3	0.73
	SQ35957	21-Mar-17	1110	1455030	5120700	< 0.010	<0.002	0.03	0.42	-	0.0053	0.018		< 3	0.97

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
	SQ35957	1-Apr-17	1220	1455030	5120700	< 0.010	0.003	0.31	0.7	-	0.0187	0.039		< 3	2.1
	SQ35957	11-Apr-17	1005	1455030	5120700	< 0.010	0.005	1.06	1.64	-	0.0082	0.032		< 3	3.9
	SQ35957	23-Apr-17	1340	1455030	5120700	< 0.010	0.009	1.82	2.2	-	0.0089	0.028		< 3	2.4
	SQ35957	6-May-17	1410	1455030	5120700	< 0.010	0.006	2.7	3.4	-	0.0027	0.033		4	12.9
	SQ35957	21-May-17	1405	1455030	5120700	< 0.010	0.003	1.72	2.1	-	0.0044	0.026		< 3	3.1
	SQ35957	30-May-17	1030	1455030	5120700	< 0.010	0.002	1.95	2.1	-	0.0028	0.014		< 3	3.5
	SQ35957	18-Jun-17	1150	1455030	5120700	< 0.010	<0.002	0.98	1.19	-	0.0044	0.015		< 3	1.32
	SQ35957	29-Jun-17	1110	1455030	5120700	< 0.010	0.002	0.47	0.74	-	0.0068	0.019		< 3	3.3
	SQ35957	11-Jul-17	1155	1455030	5120700	< 0.010	<0.002	1.14	1.4	-	0.0067	0.0117		< 3	2.4
	SQ35957	19-Jul-17	1250	1455030	5120700	< 0.010	0.003	1.1	1.41	-	0.0068	0.03		< 3	8.1
	SQ35957	6-Aug-17	900	1455030	5120700	0.028	0.006	2.7	3.1	-	0.0085	0.031		3	6
	SQ35957	26-Aug-17	1250	1455030	5120700	< 0.010	0.007	3.7	3.9	-	0.0049	0.018		< 3	5.5
D2	SQ36211	1-Sep-16	1035	1455240	5120359	0.017	0.015	4.8	5	-	0.0112	0.031		6	3.5
	SQ36211	9-Nov-16	1045	1455240	5120359	0.039	0.033	3.6	4	-	0.024	0.039		11	4.9
	SQ36211	17-Jan-17	1445	1455240	5120359	0.063	0.024	4.9	4.6	-	0.031	0.046		5	1.96
	SQ36211	21-Mar-17	1135	1455240	5120359	0.019	0.02	4.3	4.3	-	0.0068	0.02		<3	1.31
	SQ36211	30-May-17	1105	1455240	5120359	0.014	0.006	6.6	6.4	-	0.0084	0.024		<3	0.9
	SQ36211	19-Jul-17	1200	1455240	5120359	<0.010	0.004	6.2	5.4	-	0.0186	0.032		<5	0.83
BC3	SQ36212	1-Sep-16	1130	1455507	5120025	< 0.010	0.003	0.84	1.07	-	0.0005	0.01		< 3	0.87
	SQ36212	9-Nov-16	1150	1455507	5120025	< 0.010	0.005	0.38	0.81	-	0.0111	0.027		< 3	1.72
	SQ36212	17-Jan-17	1500	1455507	5120025	<0.010	0.008	2.2	2.6	-	0.009	0.024		6	1.41
	SQ36212	21-Mar-17	1005	1455507	5120025	<0.010	0.002	0.63	0.9	-	0.0022	0.016		<3	0.91
	SQ36212	30-May-17	1235	1455507	5120025	<0.010	0.004	3.2	3.4	-	0.0021	0.019		<3	2.1
	SQ36212	19-Jul-17	1105	1455507	5120025	<0.010	0.003	1.54	1.92	-	0.0075	0.035		<5	7.4
D4	SQ36213	1-Sep-16	1150	1455569	5119963	< 0.010	< 0.002	5.6	5.7	-	0.0169	0.034		5	1.56
	SQ36213	9-Nov-16	1200	1455569	5119963	< 0.010	0.003	5.3	5.7	-	0.014	0.11		113	21

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
	SQ36213	17-Jan-17	1510	1455569	5119963	<0.010	<0.002	7	6.7	-	0.02	0.02		<3	0.42
	SQ36213	21-Mar-17	1015	1455569	5119963	<0.010	<0.002	6	5.4	-	0.031	0.034		<3	0.48
	SQ36213	30-May-17	1245	1455569	5119963	<0.010	<0.002	7.4	7	-	0.028	0.038		<3	0.36
	SQ36213	19-Jul-17	1115	1455569	5119963	<0.010	<0.002	6.7	6.4	-	0.035	0.043		<4	1.02
BC5	SQ36214	1-Sep-16	1220	1455908	5119495	< 0.010	0.005	1.03	1.31	-	0.0005	0.011		< 3	0.84
	SQ36214	9-Nov-16	820	1455908	5119495	< 0.010	0.004	0.61	1.02	-	0.0105	0.027		< 3	1.35
	SQ36214	17-Jan-17	1155	1455908	5119495	< 0.010	0.007	2.5	2.9	-	0.0043	0.018		6	0.85
	SQ36214	21-Mar-17	930	1455908	5119495	< 0.010	0.002	0.89	0.96	-	0.0021	0.012		<3	0.98
	SQ36214	30-May-17	925	1455908	5119495	< 0.010	0.003	3.4	3.6	-	0.0015	0.024		<3	2.2
	SQ36214	19-Jul-17	1015	1455908	5119495	< 0.010	0.003	1.64	2.1	-	0.0086	0.036		<4	6.6
D6	SQ36215	1-Sep-16	1225	1455888	5119485	0.27	0.025	0.72	1.85	-	0.034	0.22		33	43
	SQ36215	9-Nov-16	810	1455888	5119485	0.111	0.051	0.49	1.69	-	0.148	0.27		20	16.8
	SQ36215	17-Jan-17	1150	1455888	5119485	<0.010	0.011	0.068	0.88	-	0.25	0.36		4	5.7
	SQ36215	21-Mar-17	935	1455888	5119485	0.05	0.011	0.182	1.18	-	0.169	0.24		6	4.4
	SQ36215	30-May-17	935	1455888	5119485	0.023	0.009	0.73	1.28	-	0.041	0.107		6	8.3
	SQ36215	19-Jul-17	1020	1455888	5119485	0.093	0.014	1.43	2.9	-	0.029	0.181		25	36
BC7	SQ36216	1-Sep-16	1245	1456658	5119495	< 0.010	0.008	0.85	1.18	-	0.0056	0.023		4	2.2
	SQ36216	24-Sep-16	1115	1456658	5119495	< 0.010	0.007	1.21	1.48	-	0.0053	0.013		< 3	1.11
	SQ36216	15-Oct-16	1155	1456658	5119495	0.028	0.006	0.67	1.39	-	0.0111	0.068		4	7.2
	SQ36216	30-Oct-16	1155	1456658	5119495	< 0.010	0.017	1.29	2.4	-	0.0193	0.07		4	7.6
	SQ36216	9-Nov-16	755	1456658	5119495	0.013	0.006	0.48	0.96	-	0.0179	0.039		< 3	2.6
	SQ36216	27-Nov-16	1120	1456658	5119495	< 0.010	0.011	1.73	2.3	-	0.0165	0.033		< 3	1.21
	SQ36216	10-Dec-16	1215	1456658	5119495	< 0.010	0.012	1.6	2.2	-	0.0094	0.031		5	1.81
	SQ36216	21-Dec-16	1310	1456658	5119495	< 0.010	0.013	2	2.2	-	0.0133	0.027		< 3	1.02
	SQ36216	6-Jan-17	1125	1456658	5119495	< 0.010	0.007	1.85	2.1	-	0.0083	0.023		< 3	0.94
	SQ36216	17-Jan-17	1135	1456658	5119495	< 0.010	0.008	1.89	2.2	-	0.0088	0.026		< 3	1.06

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
	SQ36216	2-Feb-17	1420	1456658	5119495	< 0.010	0.006	1.12	1.54	-	0.0107	0.016		4	1.01
	SQ36216	16-Feb-17	1000	1456658	5119495	< 0.010	0.005	1.31	1.7	-	0.0057	0.014		< 3	1.25
	SQ36216	2-Mar-17	1050	1456658	5119495	< 0.010	0.006	0.99	1.25	-	0.009	0.021		< 3	0.88
	SQ36216	21-Mar-17	910	1456658	5119495	< 0.010	0.003	0.6	0.92	-	0.0045	0.016		< 3	0.85
	SQ36216	1-Apr-17	1320	1456658	5119495	0.011	0.004	0.65	2	-	0.026	0.045		< 3	1.57
	SQ36216	11-Apr-17	1025	1456658	5119495	< 0.010	0.007	1.47	2.1	-	0.0191	0.045		< 3	3.2
	SQ36216	23-Apr-17	1355	1456658	5119495	< 0.010	0.008	2.3	2.7	-	0.0166	0.035		< 3	1.98
	SQ36216	6-May-17	1420	1456658	5119495	< 0.010	0.007	3.4	4	-	0.0099	0.031		< 3	2.3
	SQ36216	21-May-17	1440	1456658	5119495	< 0.010	0.006	2.5	2.9	-	0.0069	0.034		< 3	2.1
	SQ36216	30-May-17	0.05	1456658	5119495	< 0.010	0.003	3	3.3	-	0.0022	0.022		< 3	2.4
	SQ36216	18-Jun-17	1200	1456658	5119495	< 0.010	0.003	2.2	2.5	-	0.0053	0.015		< 3	1.13
	SQ36216	29-Jun-17	1135	1456658	5119495	< 0.010	0.003	1.05	1.39	-	0.0099	0.029		< 3	3.9
	SQ36216	11-Jul-17	1210	1456658	5119495	0.015	0.003	2.1	2.4	-	0.0128	0.026		< 3	3.6
	SQ36216	19-Jul-17	1035	1456658	5119495	< 0.010	0.005	1.59	2.3	-	0.0132	0.072		14	15.8
	SQ36216	6-Aug-17	910	1456658	5119495	0.027	0.007	3.5	4	-	0.0116	0.036		< 3	6.9
	SQ36216	26-Aug-17	1215	1456658	5119495	< 0.010	0.005	4.8	4.9	-	0.0084	0.02		< 3	3.6
D8	SQ36217	1-Sep-16	1300	1456658	5119555	< 0.010	0.003	2.9	3	-	0.027	0.039		< 3	1.11
	SQ36217	9-Nov-16	745	1456658	5119555	0.015	0.005	1.32	1.96	-	0.047	0.073		7	11.1
	SQ36217	17-Jan-17	1130	1456658	5119555	< 0.010	0.02	2.2	2.8	-	0.052	0.1		20	8.3
	SQ36217	21-Mar-17	915	1456658	5119555	< 0.010	0.018	3.1	3.3	-	0.046	0.074		7	4.2
	SQ36217	30-May-17	900	1456658	5119555	< 0.010	0.019	4.6	4.8	-	0.0121	0.034		<3	1.93
	SQ36217	19-Jul-17	1040	1456658	5119555	< 0.010	0.013	3	3.5	-	0.039	0.092		<5	7.4
BC9	SQ36218	1-Sep-16	1100	1457297	5119525	< 0.010	0.005	0.99	1.31	-	0.0031	0.02		4	1.75
	SQ36218	9-Nov-16	735	1457297	5119525	0.012	0.004	0.43	0.91	-	0.017	0.034		< 3	1.83
	SQ36218	17-Jan-17	1110	1457297	5119525	< 0.010	0.007	1.51	1.88	-	0.017	0.026		< 3	0.65
	SQ36218	21-Mar-17	855	1457297	5119525	< 0.010	0.003	0.66	0.98	-	0.0097	0.02		< 3	0.97

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
	SQ36218	30-May-17	855	1457297	5119525	< 0.010	0.004	3.1	3.2	-	0.0022	0.024		< 3	2
	SQ36218	19-Jul-17	945	1457297	5119525	0.013	0.005	1.57	2.3	-	0.0151	0.064		4	10.3
D10	SQ36219	1-Sep-16	1105	1457296	5119523	< 0.010	0.003	5.5	5.5	-	0.0148	0.027		6	1.85
	SQ36219	9-Nov-16	725	1457296	5119523	0.012	0.01	4.1	4.1	-	0.023	0.035		4	1.62
	SQ36219	17-Jan-17	1100	1457296	5119523	< 0.010	0.01	6.4	6.3	-	0.026	0.038		3	2.2
	SQ36219	21-Mar-17	900	1457296	5119523	< 0.010	0.011	3.7	3.6	-	0.035	0.042		<3	1.34
	SQ36219	30-May-17	850	1457296	5119523	0.048	0.019	9.2	8.9	-	0.04	0.071		10	4.9
	SQ36219	19-Jul-17	940	1457296	5119523	0.016	0.006	6.4	7.2	-	0.055	0.116		18	9.2
D11	SQ36220	1-Sep-16	1320	1457497	5119635	0.011	0.009	2.8	2.8	-	0.024	0.032		< 3	1.05
	SQ36220	9-Nov-16	700	1457497	5119635	0.029	0.012	1.31	1.87	-	0.043	0.072		10	4.3
	SQ36220	17-Jan-17	1045	1457497	5119635	0.013	0.01	4.1	4.3	-	0.015	0.028		7	3.1
	SQ36220	21-Mar-17	845	1457497	5119635	0.097	0.016	1.68	2.9	-	0.033	0.038		17	7.7
	SQ36220	30-May-17	835	1457497	5119635	0.013	0.011	6	6.3	-	0.0137	0.029		8	3.6
	SQ36220	19-Jul-17	930	1457497	5119635	0.033	0.014	4.7	5.1	-	0.02	0.078		22	10.7
D12	SQ36221	1-Sep-16	1335	1457827	5119665	0.011	0.004	2.2	2.4	-	0.0027	0.027		17	7.9
	SQ36221	9-Nov-16	645	1457827	5119665	0.031	0.012	1.26	2.2	-	0.0173	0.091		47	15.7
	SQ36221	17-Jan-17	1020	1457827	5119665	0.109	0.022	0.112	1.15	-	0.0158	0.198		64	19.8
	SQ36221	21-Mar-17	830	1457827	5119665	0.05	0.029	1.51	2.1	-	0.007	0.032		41	11.7
	SQ36221	30-May-17	820	1457827	5119665	<0.010	0.004	3	3.3	-	0.0017	0.016		<3	1.63
	SQ36221	19-Jul-17	910	1457827	5119665	<0.010	0.003	2.9	3.2	-	0.0053	0.02		<5	1.94
BC13	SQ35956	1-Sep-16	1350	1458110	5119560	< 0.010	0.006	2.3	2.4	-	0.0056	0.022		4	1.39
	SQ35956	24-Sep-16	1200	1458110	5119560	< 0.010	0.006	2.4	2.7	-	0.0082	0.016		< 3	0.73
	SQ35956	15-Oct-16	1515	1458110	5119560	0.019	0.006	0.83	1.47	-	0.0112	0.055		4	5.4
	SQ35956	30-Oct-16	1145	1458110	5119560	< 0.010	0.014	1.41	2.5	-	0.0185	0.072		3	6.4
	SQ35956	9-Nov-16	630	1458110	5119560	0.014	0.007	1.17	1.57	-	0.019	0.031		< 3	3.8
	SQ35956	27-Nov-16	1130	1458110	5119560	< 0.010	0.011	2.8	3.4	-	0.024	0.038		< 3	0.8

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
	SQ35956	10-Dec-16	1225	1458110	5119560	< 0.010	0.012	3.4	3.8	-	0.021	0.036		3	2.9
	SQ35956	21-Dec-16	1320	1458110	5119560	< 0.010	0.012	3.9	3.8	-	0.0137	0.02		< 3	1.09
	SQ35956	6-Jan-17	1135	1458110	5119560	< 0.010	0.009	4.1	4.2	-	0.016	0.024		< 3	1.64
	SQ35956	17-Jan-17	1010	1458110	5119560	< 0.010	0.009	3.1	3.4	-	0.015	0.028		< 3	0.96
	SQ35956	2-Feb-17	1100	1458110	5119560	< 0.010	0.005	2	2.4	-	0.0135	0.018		< 3	1.01
	SQ35956	16-Feb-17	930	1458110	5119560	< 0.010	0.005	1.74	2.1	-	0.0109	0.018		< 3	0.94
	SQ35956	2-Mar-17	1010	1458110	5119560	< 0.010	0.007	1.48	1.63	-	0.0139	0.026		< 3	1
	SQ35956	21-Mar-17	800	1458110	5119560	0.058	0.018	1.21	1.55	-	0.0145	0.025		< 3	1.11
	SQ35956	1-Apr-17	1400	1458110	5119560	< 0.010	0.01	1.5	1.73	-	0.033	0.046		< 3	1.28
	SQ35956	11-Apr-17	1200	1458110	5119560	< 0.010	0.008	2.5	3.1	-	0.037	0.053		< 3	2.1
	SQ35956	23-Apr-17	1410	1458110	5119560	< 0.010	0.011	4.2	4.5	-	0.033	0.05		< 3	1.45
	SQ35956	6-May-17	1435	1458110	5119560	< 0.010	0.008	5.3	5.7	-	0.024	0.05		<3	1.42
	SQ35956	21-May-17	1510	1458110	5119560	< 0.010	0.007	5.2	5.8	-	0.0152	0.035		3	1.86
	SQ35956	30-May-17	810	1458110	5119560	< 0.010	0.009	5.6	5.8	-	0.0163	0.031		10	3.4
	SQ35956	18-Jun-17	1215	1458110	5119560	< 0.010	0.006	4.9	4.8	-	0.0459	0.024		<3	1.03
	SQ35956	29-Jun-17	1155	1458110	5119560	< 0.010	0.005	2.7	3.3	-	0.0145	0.026		<3	3.1
	SQ35956	11-Jul-17	1235	1458110	5119560	0.016	0.005	3.9	4.2	-	0.0176	0.028		<3	3
	SQ35956	19-Jul-17	900	1458110	5119560	0.016	0.006	2.4	2.8	-	0.021	0.062		5	9.2
	SQ35956	6-Aug-17	920	1458110	5119560	0.015	0.007	5.2	5.4	-	0.0186	0.035		3	4.2
	SQ35956	26-Aug-17	1205	1458110	5119560	< 0.010	0.006	6.1	6.1	-	0.0172	0.03		<3	2.9
D14	SQ36222	1-Sep-16	1405	1458317	5119326	< 0.010	0.006	1.9	2.1	-	0.0037	0.015		< 3	0.33
	SQ36222	9-Nov-16	620	1458317	5119326	0.01	< 0.002	0.05	0.68	-	0.0054	0.038		20	7.3
	SQ36222	17-Jan-17	1000	1458317	5119326	< 0.010	< 0.002	0.005	0.4	-	0.0016	0.014		6	1.74
	SQ36222	21-Mar-17	735	1458317	5119326	< 0.010	< 0.002	0.001	0.85	-	0.002	0.008		5	1.55
	SQ36222	30-May-17	805	1458317	5119326	< 0.010	0.003	1.94	2.1	-	0.0118	0.026		6	0.65
	SQ36222	19-Jul-17	830	1458317	5119326	< 0.010	0.004	3.6	3.9	-	0.033	0.043		<3	1.47

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
D15	SQ36223	1-Sep-16	1410	1458266	5119325	< 0.010	< 0.002	0.051	0.75	-	0.0064	0.024		6	0.88
	SQ36223	9-Nov-16	615	1458266	5119325	0.014	0.002	0.001	1.26	-	0.029	0.22		31	11.1
	SQ36223	17-Jan-17	(dry)	1458266	5119325	(dry)	(dry)		(dry)	-		(dry)		(dry)	(dry)
	SQ36223	21-Mar-17	615	1458266	5119325	0.012	< 0.002	0.004	0.54	-	0.042	0.092		<3	4.3
	SQ36223	30-May-17	800	1458266	5119325	<0.010	< 0.002	0.001	0.57	-	0.014	0.031		<3	1.84
	SQ36223	19-Jul-17	825	1458266	5119325	0.011	0.005	0.66	1.72	-	0.049	0.095		<3	7.8
D16	SQ36224	1-Sep-16	1440	1458949	5119147	0.01	0.005	1.11	1.41	-	0.017	0.029		7	2.3
	SQ36224	9-Nov-16	540	1458949	5119147	0.01	0.006	0.3	0.68	-	0.044	0.063		< 3	1.16
	SQ36224	17-Jan-17	735	1458949	5119147	<0.010	< 0.002	0.023	0.31	-	0.028	0.054		4	1.36
	SQ36224	21-Mar-17	715	1458949	5119147	<0.010	0.002	0.001	0.46	-	0.02	0.04		<3	1.81
	SQ36224	30-May-17	740	1458949	5119147	0.012	0.007	3	3.3	-	0.0196	0.03		<3	0.74
	SQ36224	19-Jul-17	800	1458949	5119147	<0.010	0.007	2.8	3.4	-	0.042	0.075		<3	7
BC17	SQ35953	1-Sep-16	1500	1459110	5119040	< 0.010	0.007	2.1	2.5	-	0.0058	0.016		4	1.49
	SQ35953	24-Sep-16	1210	1459110	5119040	< 0.010	0.007	2.2	2.5	-	0.0031	0.012		< 3	1.17
	SQ35953	15-Oct-16	1535	1459110	5119040	< 0.010	0.006	0.79	1.43	-	0.0115	0.056		4	5.2
	SQ35953	30-Oct-16	1130	1459110	5119040	< 0.010	0.013	1.39	2.5	-	0.0176	0.07		6	5.9
	SQ35953	9-Nov-16	530	1459110	5119040	< 0.010	0.005	1.06	1.45	-	0.0178	0.029		< 3	1.26
	SQ35953	27-Nov-16	1145	1459110	5119040	< 0.010	0.008	2.8	3.2	-	0.023	0.029		< 3	0.71
	SQ35953	10-Dec-16	1235	1459110	5119040	< 0.010	0.011	3.1	3.6	-	0.0155	0.025		< 3	0.92
	SQ35953	21-Dec-16	1340	1459110	5119040	0.011	0.01	3.6	3.5	-	0.0166	0.024		< 3	1.33
	SQ35953	6-Jan-17	1205	1459110	5119040	< 0.010	0.007	3.7	4	-	0.0162	0.025		< 3	0.76
	SQ35953	17-Jan-17	745	1459110	5119040	< 0.010	0.006	2.8	3.1	-	0.0136	0.02		< 3	0.6
	SQ35953	2-Feb-17	935	1459110	5119040	< 0.010	0.005	1.7	2	-	0.0111	0.016		< 3	0.92
	SQ35953	16-Feb-17	900	1459110	5119040	< 0.010	0.004	1.44	1.78	-	0.0095	0.018		< 3	0.86
	SQ35953	2-Mar-17	945	1459110	5119040	< 0.010	0.006	1.21	1.46	-	0.0124	0.024		< 3	0.69
	SQ35953	21-Mar-17	705	1459110	5119040	0.022	0.009	1.1	1.35	-	0.0096	0.024		< 3	1.11

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
	SQ35953	1-Apr-17	1415	1459110	5119040	< 0.010	0.005	1.43	1.69	-	0.031	0.045		< 3	1.72
	SQ35953	11-Apr-17	1305	1459110	5119040	< 0.010	0.007	2.4	3.1	-	0.036	0.051		< 3	1.95
	SQ35953	23-Apr-17	1420	1459110	5119040	< 0.010	0.007	4	4.3	-	0.031	0.046		< 3	1.46
	SQ35953	6-May-17	1450	1459110	5119040	< 0.010	0.006	5	5.6	-	0.023	0.034		< 3	0.74
	SQ35953	21-May-17	1525	1459110	5119040	< 0.010	0.008	4.9	5.5	-	0.013	0.035		< 3	1.21
	SQ35953	30-May-17	745	1459110	5119040	< 0.010	0.006	5.4	5.7	-	0.0145	0.044		20	3.4
	SQ35953	18-Jun-17	1225	1459110	5119040	< 0.010	0.005	4.9	4.8	-	0.0148	0.019		< 3	1.26
	SQ35953	29-Jun-17	1205	1459110	5119040	< 0.010	0.004	2.6	2.8	-	0.0143	0.026		< 3	2.2
	SQ35953	11-Jul-17	1255	1459110	5119040	0.014	0.004	3.8	4.1	-	0.018	0.026		< 3	2
	SQ35953	19-Jul-17	810	1459110	5119040	< 0.010	0.006	2.5	2.8	-	0.022	0.059		5	8.6
	SQ35953	6-Aug-17	935	1459110	5119040	0.014	0.007	5	5.1	-	0.0177	0.045		5	3.9
	SQ35953	26-Aug-17	1155	1459110	5119040	< 0.010	0.005	5.8	5.8	-	0.016	0.024		< 3	1.79
W18	SQ35955	1-Sep-16	1510	1459080	5119020	< 0.010	< 0.002	0.85	0.94	-	0.0016	0.005		< 3	0.32
	SQ35955	24-Sep-16	1215	1459080	5119020	< 0.010	< 0.002	1.37	1.48	-	0.0041	< 0.004		< 3	0.26
	SQ35955	15-Oct-16	1540	1459080	5119020	< 0.010	< 0.002	0.47	0.61	-	0.0047	0.011		< 3	1.17
	SQ35955	30-Oct-16	1125	1459080	5119020	< 0.010	< 0.002	0.36	0.48	-	0.0039	0.008		< 3	1.24
	SQ35955	9-Nov-16	525	1459080	5119020	< 0.010	< 0.002	0.38	0.45	-	0.0034	0.004		< 3	0.19
	SQ35955	27-Nov-16	1155	1459080	5119020	< 0.010	< 0.002	0.82	0.95	-	0.0046	0.004		< 3	0.34
	SQ35955	10-Dec-16	1240	1459080	5119020	< 0.010	< 0.002	0.96	1.12	-	0.0041	0.004		< 3	0.44
	SQ35955	21-Dec-16	1355	1459080	5119020	< 0.010	< 0.002	1.54	1.41	-	0.0044	< 0.004		< 3	0.33
	SQ35955	6-Jan-17	1215	1459080	5119020	< 0.010	< 0.002	2.4	2.4	-	0.0027	< 0.004		< 3	0.13
	SQ35955	17-Jan-17	755	1459080	5119020	< 0.010	< 0.002	2.3	2.5	-	0.0016	< 0.004		< 3	0.14
	SQ35955	2-Feb-17	1000	1459080	5119020	< 0.010	< 0.002	1.41	1.49	-	0.0045	< 0.004		< 3	0.09
	SQ35955	16-Feb-17	845	1459080	5119020	< 0.010	< 0.002	1.65	1.86	-	0.0041	< 0.004		< 3	0.24
	SQ35955	2-Mar-17	935	1459080	5119020	< 0.010	< 0.002	2.3	2.3	-	0.0043	< 0.004		< 3	0.1
	SQ35955	21-Mar-17	655	1459080	5119020	< 0.010	< 0.002	0.94	1.03	-	0.0029	< 0.004		< 3	0.31

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
	SQ35955	1-Apr-17	1420	1459080	5119020	< 0.010	< 0.002	0.69	0.62	-	0.0035	0.01		< 3	0.28
	SQ35955	11-Apr-17	1320	1459080	5119020	< 0.010	< 0.002	0.95	1.08	-	0.0027	0.007		< 3	0.44
	SQ35955	23-Apr-17	1425	1459080	5119020	< 0.010	< 0.002	1.17	1.27	-	0.0011	0.005		< 3	0.55
	SQ35955	6-May-17	1500	1459080	5119020	<0.010	<0.002	1.44	1.63	-	0.0023	0.007		<3	0.41
	SQ35955	21-May-17	1535	1459080	5119020	<0.010	<0.002	2.5	2.7	-	0.0021	0.006		<3	0.38
	SQ35955	30-May-17	720	1459080	5119020	<0.010	<0.002	3.4	3.5	-	0.0011	0.006		<3	0.11
	SQ35955	18-Jun-17	1230	1459080	5119020	<0.010	<0.002	2.9	3	-	0.0034	0.007		<3	0.24
	SQ35955	29-Jun-17	1210	1459080	5119020	<0.010	<0.002	2.6	2.5	-	0.0041	0.007		<3	0.48
	SQ35955	11-Jul-17	1305	1459080	5119020	<0.010	<0.002	1.6	1.64	-	0.0035	0.005		<3	0.33
	SQ35955	19-Jul-17	815	1459080	5119020	<0.010	<0.002	1.11	1.06	-	0.0036	0.004		<3	0.14
	SQ35955	6-Aug-17	945	1459080	5119020	<0.010	<0.002	1.69	1.79	-	0.0038	0.008		<3	0.3
	SQ35955	26-Aug-17	1140	1459080	5119020	<0.010	<0.002	1.34	1.37	-	0.0029	0.005		<3	0.29
J37/0092	J37/0092	23-Aug-16	1450	1455178	5120620	< 0.010	< 0.002	4.6		4.6	0.0137		0.015		
	J37/0092	9-Nov-16	1120	1455178	5120620	0.015	< 0.002	4.6		4.6	0.0166		0.014		
	J37/0092	17-Jan-17	1430	1455178	5120620	0.016	< 0.002	6.4		6	0.0154		0.016		
	J37/0092	21-Mar-17	1150	1455178	5120620	< 0.010	< 0.002	4.7		4.1	0.015		0.026		
	J37/0092	30-May-17	1050	1455178	5120620	< 0.010	< 0.002	6.6		5.7	0.014		0.016		
	J37/0092	19-Jul-17	1145	1455178	5120620	< 0.010	< 0.002	5.8		5.8	0.0144		0.013		
J37/0185	J37/0185	25-Aug-16	1105	1455382	5121799	< 0.010	< 0.002	2.7		2.7	0.0186		0.017		
	J37/0185	9-Nov-16	930	1455382	5121799	0.024	< 0.002	2.5		2.6	0.022		0.018		
	J37/0185	17-Jan-17	1245	1455382	5121799	0.012	< 0.002	2.7		2.7	0.0044		0.019		
	J37/0185	21-Mar-17	1220	1455382	5121799	0.01	< 0.002	2.9		2.7	0.021		0.02		
	J37/0185	30-May-17	1215	1455382	5121799	<0.010	< 0.002	2.9		2.7	0.0199		0.021		
	J37/0185	19-Jul-17	1340	1455382	5121799	<0.010	< 0.002	3		2.8	0.018		0.017		
J37/0202	J37/0202	24-Aug-16	1245	1458382	5120346	0.011	< 0.002	0.004		0.017	0.0119		0.019		
	J37/0202	9-Nov-16	1250	1458382	5120346	0.014	< 0.002	0.041		0.067	0.033		0.034		

Site name		Date	Time	NZTMX	NZTMY	Ammonia Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Dissolved Nitrogen (mg/L)	Dissolved Reactive Phosphorus (mg/L)	Total Phosphorus (mg/L)	Total Dissolved Phosphorus (mg/L)	Total Suspended Solids (mg/L)	Turbidity (NTU)
	J37/0202	17-Jan-17	NA	1458382	5120346	NA	NA	NA		NA	NA		NA		
	J37/0202	21-Mar-17	NA	1458382	5120346	NA	NA	NA		NA	NA		NA		
	J37/0202	30-May-17	NA	1458382	5120346	NA	NA	NA		NA	NA		NA		
	J37/0202	19-Jul-17	NA	1458382	5120346	NA	NA	NA		NA	NA		NA		
J37/0297	J37/0297	24-Aug-16	1510	1455586	5121388	< 0.010	< 0.002	4.5		4.5	0.0106		0.01		
	J37/0297	9-Nov-16	1025	1455586	5121388	< 0.010	< 0.002	4.2		4.3	0.012		0.016		
	J37/0297	17-Jan-17	1350	1455586	5121388	0.022	< 0.002	6.4		6.2	0.0053		0.008		
	J37/0297	21-Mar-17	1240	1455586	5121388	< 0.010	< 0.002	4		3.7	0.0109		0.02		
	J37/0297	30-May-17	1125	1455586	5121388	0.01	< 0.002	8		6.9	0.0091		0.011		
	J37/0297	19-Jul-17	1310	1455586	5121388	< 0.010	< 0.002	5.8		5.7	0.01		0.01		
SQ36226	SQ36226	23-Aug-16	1745	1456216	5120372	< 0.010	< 0.002	7.3		6.8	0.0134		0.014		
	SQ36226	9-Nov-16	1220	1456216	5120372	0.026	0.004	6.4		6	0.0188		0.02		
	SQ36226	17-Jan-17	1530	1456216	5120372	0.013	< 0.002	10.9		8.3	0.0192		0.018		
	SQ36226	21-Mar-17	950	1456216	5120372	< 0.010	< 0.002	7.2		6.6	0.0152		0.019		
	SQ36226	30-May-17	1305	1456216	5120372	< 0.010	< 0.002	10.7		10.5	0.024		0.024		
	SQ36226	19-Jul-17	1050	1456216	5120372	< 0.010	< 0.002	8.7		7.8	0.0148		0.014		

Appendix J: Flow relationships

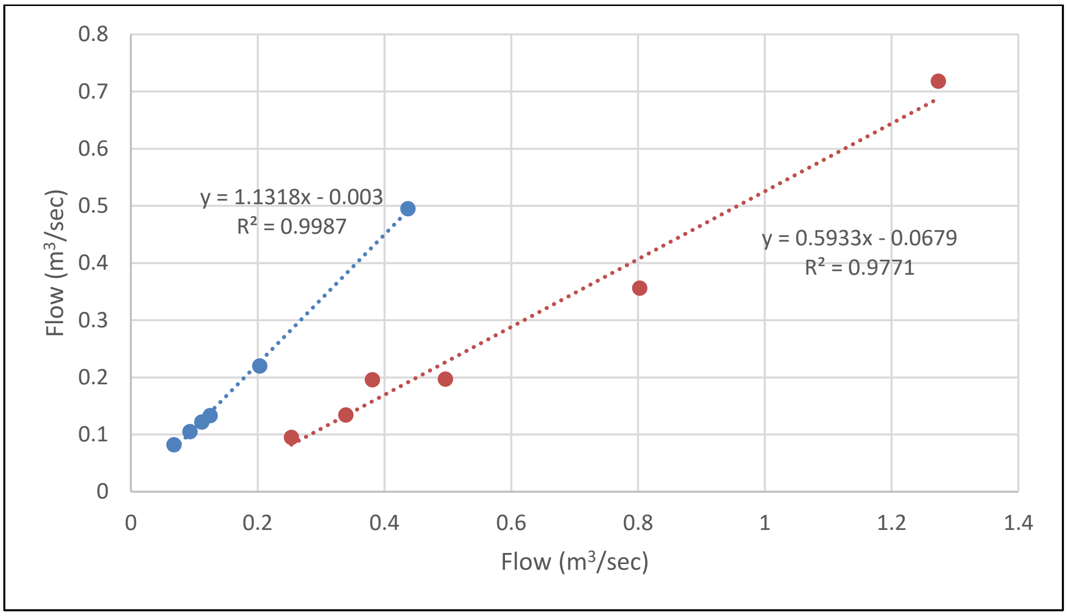

Figure K-1: Flow relationship between BC17 (Barkers Creek at upstream Waihi River) and BC13 (Barkers Creek at Sercombe Road) in blue and flow relationship between W18 (Waihi River at upstream Barkers Creek) and Environment Canterbury's Waihi River at Waimarie flow monitoring site in red

Appendix K: Daily nitrate-nitrogen and DRP loads

Table K-1: Daily nutrient load estimates for fortnightly sampling runs at Barkers Creek upstream Waihi River confluence (BC17) and Waihi River upstream of Barkers Creek confluence (W18)

Sample data	BC17 flow (m^3/sec)	Nitrate-nitrogen (mg/L)	DRP (mg/L)	Nitrate-nitrogen load (kg/day)	DRP load (kg/day)	W18 flow (m^3/sec)	Nitrate-nitrogen (mg/L)	DRP (mg/L)	Nitrate-nitrogen load (kg/day)	DRP load (kg/day)
1-Sep-16	0.129	2.1	0.006	23.329	1.052	0.294	0.850	0.002	21.584	0.118
24-Sep-16	0.117	2.2	0.003	22.230	0.589	0.208	1.370	0.004	24.642	0.485
15-Oct-16	0.354	0.79	0.012	24.170	0.785	1.405	0.470	0.005	57.069	0.191
30-Oct-16	0.544	1.39	0.018	65.365	2.114	1.349	0.360	0.004	41.948	0.121
9-Nov-16	0.119	1.06	0.018	10.887	1.630	0.544	0.380	0.003	17.864	0.112
27-Nov-16	0.217	2.8	0.023	52.389	5.564	0.431	0.820	0.005	30.531	0.326
10-Dec-16	0.252	3.1	0.016	67.600	4.152	0.350	0.960	0.004	29.034	0.340
21-Dec-16	0.187	3.6	0.017	58.206	5.163	0.254	1.540	0.004	33.775	0.585
6-Jan-17	0.172	3.7	0.016	55.145	5.179	0.295	2.400	0.003	61.260	0.560
17-Jan-17	0.099	2.8	0.014	23.901	3.290	0.218	2.300	0.002	43.338	0.318
2-Feb-17	0.078	1.7	0.011	11.463	1.630	0.238	1.410	0.005	28.983	0.548
16-Feb-17	0.054	1.44	0.010	6.778	1.182	0.187	1.650	0.004	26.642	0.584
2-Mar-17	0.055	1.21	0.012	5.744	1.296	0.195	2.300	0.004	38.720	0.854
21-Mar-17	0.077	1.1	0.010	7.323	0.912	0.362	0.940	0.003	29.421	0.236
1-Apr-17	0.163	1.43	0.031	20.098	3.830	0.556	0.690	0.004	33.126	0.209
11-Apr-17	0.284	2.4	0.036	58.934	7.465	0.834	0.950	0.003	68.415	0.222
23-Apr-17	0.302	4	0.031	104.504	10.714	0.557	1.170	0.001	56.325	0.111
6-May-17	0.307	5	0.023	132.726	9.936	0.319	1.440	0.002	39.654	0.286
21-May-17	0.310	4.9	0.013	131.410	5.504	0.344	2.500	0.002	74.237	0.454
30-May-17	0.231	5.4	0.015	107.731	6.765	0.269	3.400	0.001	79.031	0.323
18-Jun-17	0.151	4.9	0.015	64.055	6.266	0.252	2.900	0.003	63.063	0.852
29-Jun-17	0.245	2.6	0.014	54.973	3.212	0.447	2.600	0.004	100.397	0.921
11-Jul-17	0.301	3.8	0.018	98.839	5.910	0.357	1.600	0.004	49.374	0.484
19-Jul-17	0.518	2.5	0.022	111.990	4.752	0.823	1.110	0.004	78.972	0.345
6-Aug-17	0.565	5	0.018	243.913	7.646	0.676	1.690	0.004	98.705	0.555
26-Aug-17	0.439	5.8	0.016	219.787	8.018	0.684	1.340	0.003	79.215	0.336

Appendix L: Nitrate-nitrogen and DRP load mass balance for hotspot identification

Table L-1: Nitrate-nitrogen load mass balance for hotspot identification

	Site	Site number	1/9/2016		9/11/2016		17/1/2017		21/3/2017		30/5/2017		19/7/2017		Daily average		Annual average	
			kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	t/year	% of total export
INPUT	Barkers Creek at McKeown Road (recorder)	BC1	0.34	1.5%	0.19	1.5%	1.83	7.2%	0.06	0.8%	7.58	7.4%	21.48	20.1%	5.25	11.4%	1.92	11.4%
	Drain at downstream McKeown Road	D2	2.49	11.2%	1.87	15.3%	4.23	16.7%	0.74	9.5%	9.12	8.9%	7.50	7.0%	4.33	9.4%	1.58	9.4%
	Drain at downstream Saywell Ford	D4	1.45	6.6%	0.92	7.5%	2.42	9.5%	2.07	26.6%	3.20	3.1%	4.63	4.3%	2.45	5.3%	0.89	5.3%
	Rokonui Drain at upstream Barkers confluence	D6	0.37	1.7%	0.34	2.8%	0.02	0.1%	0.03	0.4%	0.44	0.4%	0.68	0.6%	0.31	0.7%	0.11	0.7%
	Middlemiss Drain at upstream Barkers confluence	D8	2.26	10.2%	1.03	8.4%	1.33	5.2%	1.34	17.2%	3.18	3.1%	4.15	3.9%	2.21	4.8%	0.81	4.8%
	Water Race at upstream Barkers confluence	D10	9.50	42.9%	7.44	61.1%	10.51	41.4%	3.84	49.2%	40.54	39.5%	26.54	24.8%	16.39	35.5%	5.98	35.5%

	Morning Glory at upstream Barkers confluence	D11	1.94	8.7%	0.91	7.4%	6.02	23.7%	0.73	9.3%	11.92	11.6%	8.12	7.6%	4.94	10.7%	1.80	10.7%
	Drain at upstream Sercombe	D12	0.19	0.9%	0.11	0.9%	0.01	0.04%	0.26	3.4%	0.26	0.3%	0.50	0.5%	0.22	0.5%	0.81	0.5%
	Sercombe North Drain at upstream Barkers	D14	0.33	1.5%	0.004	0.04%	0.001	0.003%	-	-	0.17	0.2%	0.62	0.6%	0.19	0.4%	0.07	0.4%
	Sercombe South Drain at upstream Barkers	D15	0.004	0.02%	0.0001	0.0007%	-	-	0.0003	0.0044%	0.0001	0.0001%	0.17	0.2%	0.03	0.06%	0.01	0.06%
	Drain at upstream Barkers/Waihi confluence	D16	0.19	0.9%	0.10	0.9%	0.002	0.01%	0.00009	0.00001%	0.78	0.8%	2.66	2.5%	0.62	1.35%	0.23	1.35%
OUTPUT	Barkers Creek at upstream Waihi River	BC17	22.14	-	12.18	-	25.40	-	7.80	-	102.64	-	106.92	-	46.18	-	16.86	-
BALANCE			3.08	13.9%	-0.72	-5.9%	-0.97	-3.83%	-1.28	-16.42%	25.45	24.8%	29.86	27.93%	9.24	20.0%	3.37	20%

Table L-2: DRP load mass balance for hotspot identification

	Site	Site number	1/09/2016		9/11/2016		17/01/2017		21/03/2017		30/05/2017		19/07/2017		Daily average		Annual average	
			kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	kg/day	% of total export	t/year	% of total export
INPUT	Barkers Creek at McKeown Road (recorder)	BC1	0.0016	2.54%	0.0504	24.63 %	0.0049	3.97%	0.0110	16.16%	0.0109	3.95%	0.1328	14.11%	0.0352	12.64 %	0.0129	12.64%
	Drain at downstream McKeown Road	D2	0.0058	9.50%	0.0124	6.08%	0.0268	21.71%	0.0012	1.73%	0.0116	4.21%	0.0225	2.39%	0.0134	4.80%	0.0049	4.80%
	Drain at downstream Saywell Ford	D4	0.0044	7.17%	0.0024	1.18%	0.0069	5.60%	0.0107	15.75%	0.0121	4.39%	0.0242	2.57%	0.0101	3.63%	0.0037	3.63%
	Rokonui Drain at upstream Barkers confluence	D6	0.0176	28.83%	0.1023	50.01 %	0.0648	52.52%	0.0292	42.94%	0.0248	9.00%	0.0138	1.46%	0.0421	15.09 %	0.0154	15.09%
	Middlemiss Drain at upstream Barkers confluence	D8	0.0210	34.34%	0.0365	17.87 %	0.0314	25.49%	0.0199	29.22%	0.0084	3.03%	0.0539	5.73%	0.0285	10.23 %	0.0104	10.23%
	Water Race at upstream Barkers confluence	D10	0.0256	41.83%	0.0417	20.40 %	0.0427	34.59%	0.0363	53.35%	0.1763	63.95%	0.2281	24.24%	0.0918	32.90 %	0.0335	32.90%

	Morning Glory at upstream Barkers confluence	D11	0.0166	27.13%	0.0297	14.53 %	0.0220	17.86%	0.0143	20.96%	0.0272	9.88%	0.0346	3.67%	0.0241	8.63%	0.0088	8.63%
	Drain at upstream Sercombe	D12	0.0002	0.38%	0.0015	0.73%	0.0014	1.11%	0.0012	1.78%	0.0001	0.05%	0.0009	0.10%	0.0009	0.32%	0.0003	0.32%
	Sercombe North Drain at upstream Barkers	D14	0.0006	1.05%	0.0005	0.23%	0.0003	0.22%	0.0002	0.25%	0.0010	0.37%	0.0057	0.61%	0.0014	0.49%	0.0005	0.49%
	Sercombe South Drain at upstream Barkers	D15	0.0006	0.90%	0.0025	1.22%	0.0000	0.00%	0.0036	5.34%	0.0012	0.44%	0.0127	1.35%	0.0034	12.64 %	0.0013	12.64%
	Drain at upstream Barkers/Waihi confluence	D16	0.0029	4.80%	0.0152	7.43%	0.0024	1.96%	0.0017	2.54%	0.0051	1.84%	0.0399	4.24%	0.0112	4.02%	0.0041	4.02%
OUTPUT	Barkers Creek at upstream Waihi River	BC17	0.0611		0.2045		0.1234		0.0680		0.2756		0.9409		0.2789		0.1018	-
BALANCE			-0.0358		-0.0907		-0.0802		-0.0612		-0.0031		0.3718					